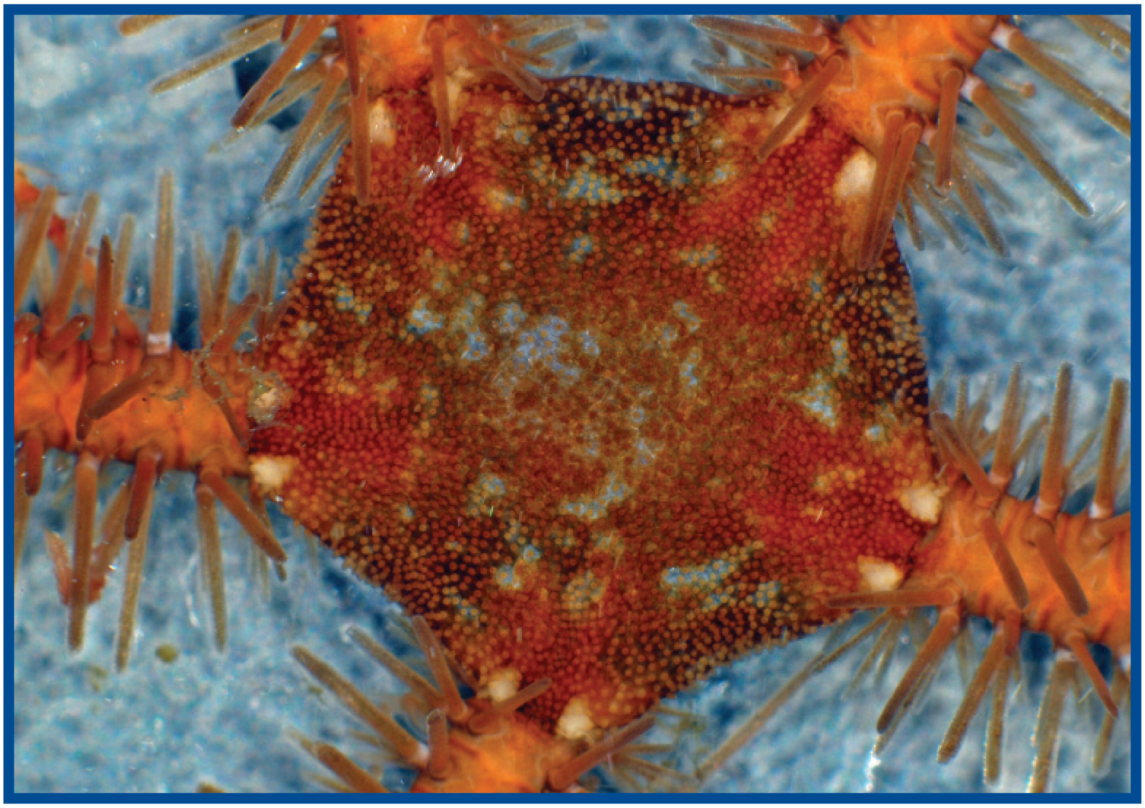
THE CITY OF SAN DIEGO

Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant) 2010



City of San Diego
Ocean Monitoring Program

Public Utilities Department
Environmental Monitoring and Technical Services Division

THE CITY OF SAN DIEGO

June 30, 2011

Mr. David Gibson, Executive Officer
Regional Water Quality Control Board
San Diego Region
9174 Sky Park Court, Suite 100
San Diego, CA 92123

Attention: POTW Compliance Unit

Dear Sir:

Enclosed on CD is the 2010 Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, South Bay Water Reclamation Plant as required per NPDES Permit No. CA0109045, Order No. R9-2006-067. This report contains data summaries, analyses and interpretations of the various portions of the ocean monitoring program, including oceanographic conditions, water quality, sediment characteristics, macrobenthic communities, demersal fishes and megabenthic invertebrates, and bioaccumulation of contaminants in fish tissues. These data are also presented in the International Boundary and Water Commission's annual report for discharge from the International Wastewater Treatment Plant (NPDES Permit No. CA0108928, Order No. 96-50).

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, I certify that the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Sincerely,

Steve Meyer
Deputy Public Utilities Director

SM/tds

Enclosure: CD containing PDF file of this report

cc: U.S. Environmental Protection Agency, Region 9
Department of Environmental Health, San Diego County
Division of Water Quality, State Resources Control Board

Environmental Monitoring and Technical Services Division • Public Utilities
2392 Kincaid Road • San Diego, CA 92101-0811
Tel (619) 758-2300 Fax (619) 758-2309

Annual Receiving Waters Monitoring Report

for the

South Bay Ocean Outfall

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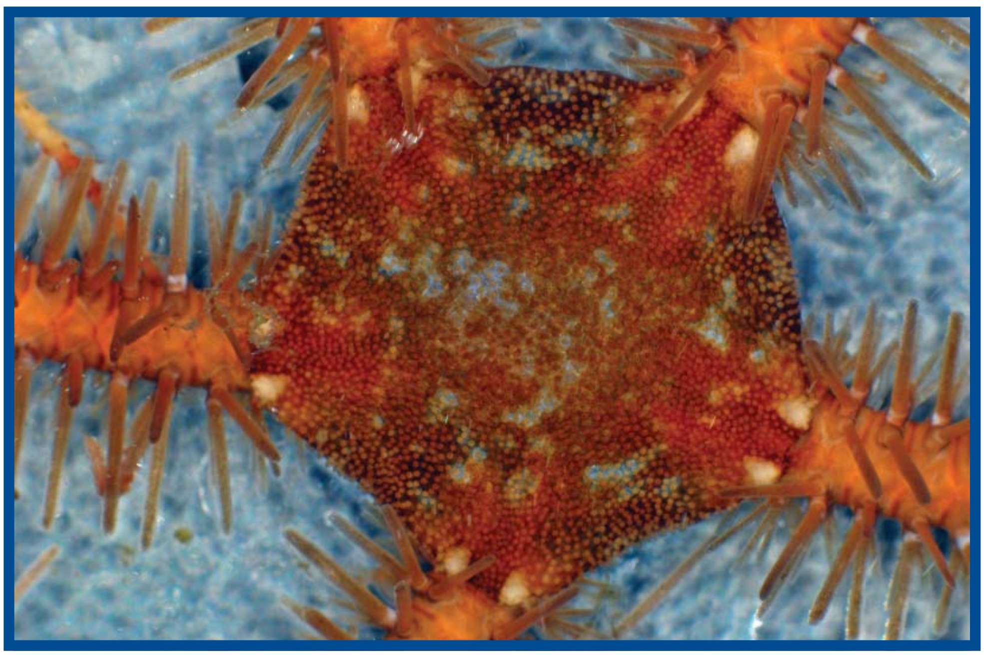

Prepared by:

City of San Diego
Ocean Monitoring Program
Public Utilities Department
Environmental Monitoring and Technical Services Division

June 2011

Timothy D. Stebbins, Editor
Ami K. Latker, Managing Editor

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Acronyms and Abbreviations

ADCP	Acoustic Doppler Current Profiler
ANOSIM	Analysis of Similarity
APHA	American Public Health Association
APT	Advanced Primary Treatment
AUV	Automated Underwater Vehicle
BACIP	Before-After-Control-Impact-Paired
BOD	Biochemical Oxygen Demand
BRI	Benthic Response Index
χ^2	Pearson's Chi-square Analyses test statistic
CCS	California Current System
CDHS	California State Department of Health Services
CFU	Colony Forming Units
cm	centimeter
CSDMML	City of San Diego Marine Microbiology Laboratory
CTD	Conductivity, Temperature, Depth instrument
DDT	Dichlorodiphenyltrichloroethane
df	degrees of freedom
DO	Dissolved Oxygen
ELAP	Environmental Laboratory Accreditation Program
EMAP	Environmental Monitoring and Assessment Program
EMTS	Environmental Monitoring and Technical Services
ERL	Effects Range Low
ERM	Effects Range Mediam
F:T	Fecal to Total coliform ratio
FIB	Fecal Indicator Bacteria
ft	feet
FTR	Fecal to Total coliform Ratio criterion
g	gram
H'	Shannon diversity index
HCB	Hexachlorobenzene
HCH	Hexachlorocylclohexane
IGODS	Interactive Geographical Ocean Data System
in	inches
IR	Infrared
IWTP	International Wastewater Treament Plant
J'	Pielou's evenness index
kg	kilogram
km	kilometer
km^2	square kilometer
L	Liter
m	meter
m^2	square meter
MDL	Method Detection Limit
nMDS	Non-metric Multidimensional Scaling
mg	milligram

mgd	millions of gallons per day
ml	maximum length
mL	milliliter
mm	millimeter
MODIS	Moderate Resolution Imaging Spectroradiometer
MRP	Monitoring and Reporting Program
mt	metric ton
n	sample size
N	number of observations used in a Chi-square analysis
ng	nanograms
no.	number
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NWS	National Weather Service
O&G	Oil and Grease
OEHHA	California Office of Environmental Health Hazard Assessment
OI	Ocean Imaging
p	probability
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PDO	Pacific Decadal Oscillation
pH	Acidity/Alkalinity value
PLOO	Point Loma Ocean Outfall
PLWTP	Point Loma Wastewater Treatment Plant
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
PRIMER	Plymouth Routines in Multivariate Ecological Research
psu	practical salinity units
r	Pearson correlation coefficient
r_s	Spearman rank correlation coefficient
ROV	Remotely Operated Vehicle
RWQCB	Regional Water Quiality Control Board
SABWTP	San Antonio de los Buenos Wastewater Treatment Plant
SBOO	South Bay Ocean Outfall
SBWRP	South Bay Water Reclamation Plant
SCB	Southern Califonia Bight
SCBPP	Southern California Bight Pilot Project
SD	Standard Deviation
SIMPER	Similarity Percentages Routine
SIMPROF	Similarity Profile Analysis
SIO	Scripps Institution of Oceanography
sp	species (singular)
spp	species (plural)
SSM	Sub-surface Salinity Minimum

Acronyms and Abbreviations *(continued)*

SWRCB	Califonia State Water Resources Control Board
tDDT	total DDT
TN	Total Nitrogen
TOC	Total Organic Carbon
tPAH	total PAH
tPCB	total PCB
TSS	Total Suspended Solids
TVS	Total Volatile Solids
USEPA	United States Environmental Protection Agency
USFDA	United States Food and Drug Administration
USGS	United States Geological Survey
USIBWC	United States International Boundary and Water Commission
wt	weight
yr	year
ZID	Zone of Initial Dilution
α	alpha, the probability of creating a type I error
μg	micrograms
π	summed absolute distances test statistic

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Technical Editors:
T. Stebbins, A. Latker, P. Vroom

Production Editors:
E. Moore, N. Haring, R. Gartman, M. Nelson, A. Davenport

GIS Graphics:
M. Kasuya, D. Olson, J. Pettis Schallert

Cover Photo:
The brittle star *Ophiacantha diplasia* H. L. Clark, 1911 collected off southern San Diego at a depth of 105 m during the Bight'08 Regional Monitoring Program. Photo by Veronica Rodriguez-Villanueva.

Acknowledgments:
We are grateful to the personnel of the City's Marine Biology, Marine Microbiology, and Wastewater Chemistry Services Laboratories for their assistance in the collection and/or processing of all samples, and for discussions of the results. The completion of this report would not have been possible without their continued efforts and contributions. We would especially like to thank A. Davenport, W. Enright, M. Kasuya, M. Nelson, D. Olson, L. Othman, J. Pettis Schallert, R. Velarde, and L. Wiborg for their critical reviews of various chapters of this report. Complete staff listings for the above labs and additional details concerning relevant QA/QC activities for the receiving waters monitoring data reported herein are available online in the 2010 EMTS Division Laboratory Quality Assurance Report (www.sandiego.gov/mwwd/environment/reports.shtml).

How to cite this document:
City of San Diego. (2011). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

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Executive Summary

Executive Summary

The City of San Diego (City) conducts extensive ocean monitoring to evaluate potential environmental effects from the discharge of treated wastewater to the Pacific Ocean via the South Bay Ocean Outfall (SBOO). The data collected are used to determine compliance with receiving water conditions as specified in the National Pollution Discharge Elimination System (NPDES) permits for the City's South Bay Water Reclamation Plant (SBWRP) and the International Wastewater Treatment Plant (IWTP) operated by the United States International Boundary and Water Commission (USIBWC). Since treated effluent from the SBWRP and IWTP commingle before being discharged to the ocean through the SBOO, a coordinated single monitoring and reporting program approved by the San Diego Regional Water Quality Control Board (RWQCB) and United States Environmental Protection Agency (USEPA) is conducted to comply with both permits.

The primary objectives of the ocean monitoring program for the South Bay outfall region are to: (a) measure compliance with NPDES permit requirements and California Ocean Plan (Ocean Plan) standards, (b) monitor changes in ocean conditions over space and time, and (c) assess any impacts of wastewater discharge or other man-made or natural influences on the local marine environment, including effects on water quality, sediment conditions and marine life. The monitoring region encompasses an area of approximately 345 km^2 (~133 mi^2), which is centered around the SBOO discharge site located approximately 5.6 km offshore at a depth of 27 m. Shoreline monitoring extends from Coronado (San Diego) southward to Playa Blanca in northern Baja California (Mexico), while regular offshore monitoring occurs in adjacent waters overlying the continental shelf at depths of about 9 to 55 m.

Prior to the initiation of wastewater discharge in 1999, the City conducted a 3½ year baseline study designed to characterize and document background conditions in the South Bay outfall region. Additionally, a larger-scale regional survey of benthic conditions is typically conducted each year at randomly selected sites ranging from northern San Diego County to the USA/Mexico border. These regional surveys are useful for evaluating patterns and trends over larger geographic areas, thus providing additional information to help distinguish possible reference areas from sites impacted by anthropogenic influences. The results of the 2010 regional survey off San Diego are presented herein.

The receiving waters monitoring activities for the South Bay outfall region are separated into several major components that are organized into nine chapters in this report. Chapter 1 presents a general introduction and overview of the ocean monitoring program, while chapters 2-7 discuss monitoring results for calendar year 2010. Specifically, in Chapter 2, data characterizing ambient physical and chemical oceanographic parameters and water mass transport for the South Bay outfall region are evaluated. Chapter 3 presents the results of water quality monitoring conducted along the shore and in local coastal waters, including measurements of fecal indicator bacteria (FIB) to determine compliance with Ocean Plan water contact standards. Assessments of benthic sediment quality and the status of soft-bottom macrobenthic invertebrate communities are presented in Chapters 4 and 5, respectively. Chapter 6 presents the results of trawling activities designed to monitor communities of bottom dwelling (demersal) fishes and megabenthic invertebrates. Bioaccumulation assessments to determine contaminant loads in the tissues of local fishes captured via trawls or by hook and line are presented in Chapter 7. Results of the summer 2010 San Diego regional survey of sediment conditions and benthic macrofaunal communities are presented in Chapters 8 and 9, respectively. In addition to the above activities, the City and USIBWC support other projects relevant to assessing the quality and movement of ocean waters in the region. One such project involves aerial and satellite imaging of the San Diego/Tijuana coastal region, the results for 2010 which are incorporated into Chapters 2 and 3.

This report focuses on the results and conclusions of all ocean monitoring activities conducted in the South Bay outfall region from January 2010 through December 2010. An overview and summary of the main findings for each of the major program components are included below.

Oceanographic Conditions

The South Bay outfall region was characterized by typical oceanographic conditions in 2010. This included seasonal patterns such as localized upwelling with corresponding phytoplankton blooms in the spring and summer, maximum stratification (layering) of the water column in late summer and early fall, and reduced stratification during the winter. Although some differences in salinity were observed near the discharge site, it was evident that any variation among stations was small and restricted to a highly localized area. Aerial imagery observations confirmed that the wastewater plume reached near-surface waters directly above the SBOO discharge site during the months of January, February, March and December when the water column was weakly stratified. In contrast, the plume remained deeply submerged between April and November when stratification was greater. Overall, ocean conditions during the year were consistent with patterns that have been well documented for southern California and northern Baja California. These findings suggest that natural factors such as upwelling of deep ocean waters and effects of widespread climatic events (e.g., El Niño/La Niña oscillations) continue to explain most of the temporal and spatial variability observed in the coastal waters off southern San Diego.

Water Quality

There was no evidence that contaminated waters associated with wastewater discharge via the SBOO reached nearshore recreational waters off southern San Diego in 2010. Although elevated FIB levels were detected in seawater samples collected along or near the shore during winter months, this contamination did not appear to be due to shoreward transport of the wastefield. Instead, the contamination was likely the result of heavy rainfall that increased outflows and the dispersion of associated turbidity plumes from the Tijuana River (USA) and Los Buenos Creek (Mexico). For example, 85% or more of all elevated FIBs recorded at the shore and kelp stations occurred during the wet season when rainfall was greatest. This general relationship between increased rainfall and high bacteria counts in local waters has remained consistent since monitoring began, including the 3–4 year period prior to wastewater discharge. The majority of elevated FIBs reported during the summer when rainfall was minimal occurred at shore stations located south of the international border and near known sources of contamination that are not associated with the SBOO. Most of the elevated FIB levels found close to the outfall were detected at a few nearfield sites located within 1000 m of the diffuser legs and at depths of 18 m or more.

Bacterial compliance levels were summarized as the number of days that each of the shore and kelp bed stations located in U.S. waters exceeded various Ocean Plan standards during each month. Due to regulatory changes that became effective August 1, 2010, compliance was assessed using the water contact standards specified in the 2001 Ocean Plan for samples collected from January 1 through July 31, 2010, whereas samples collected after August 1, 2010 were assessed using 2005 Ocean Plan standards. Bacterial compliance during the year was relatively high throughout the year with an overall compliance rate of 87% at these stations.

Sediment Conditions

The composition of benthic sediments sampled at the 27 regular (fixed-grid) South Bay outfall stations in 2010 varied from fine silts to very coarse sands or other relatively large particles (e.g., gravel, shells), and was similar to patterns seen in previous years. No apparent spatial relationship between sediment particle size and proximity to the discharge site exists, nor has there been any substantial increase in fine sediments at nearfield stations or throughout the region since wastewater discharge began. Instead, the diversity of sediment types reflects multiple geological origins, or suggests complex patterns of transport and deposition from sources such as the Tijuana River and San Diego Bay.

Overall sediment quality at the South Bay outfall monitoring sites in 2010 was similar to previous years, and there was no evidence of contaminant accumulation associated with wastewater discharge. Concentrations of various trace metals, indicators of organic loading, pesticides (e.g., DDT), and PCBs varied widely throughout the region, with no patterns that could be attributed to the outfall or any other point sources. Instead, the accumulation of contaminants in sediments continued to be linked to natural environmental heterogeneity. For example, concentrations of organic loading indicators such as total organic carbon and total nitrogen, along with several metals, were typically higher at sites characterized by finer sediments, a pattern consistent with results from other studies. In addition, most contaminants detected in local sediments were within the range of predischarge values reported for the region. Finally, the potential for environmental degradation by the contaminants detected during the year was evaluated using the effects-range low (ERL) and effects-range median (ERM) sediment quality guidelines when available. During 2010, there were no exceedances of the ERL or ERM thresholds.

Macrobenthic Communities

Benthic macrofaunal assemblages surrounding the SBOO were similar in 2010 to those encountered during previous years, including the period prior to wastewater discharge. These assemblages were typical of those that occur in other sandy, shallow- and mid-depth habitats throughout the Southern California Bight (SCB). For example, most of the sandier, shallower sites contained high abundances of the spionid polychaete *Spiophanes norrisi*, a species characteristic of similar habitats and assemblages in the SCB. In contrast, slightly different macrofaunal assemblages occurred at mid-depth stations that had finer sediments characteristic of much of the southern California mainland shelf.

Benthic community structure parameters such as species richness and total abundance varied with depth and sediment type, with no clear patterns relative to the SBOO discharge area. Instead, spatial patterns in macrofaunal abundance appear to be largely driven by changes in *S. norrisi* populations. The range of abundance values for macrobenthic invertebrates in 2010 was similar to that seen in previous years, and results for the benthic response index (BRI) were generally characteristic of reference conditions for the SCB. In addition, changes that did occur during the year were similar in magnitude to those that have occurred previously in southern California waters, and correspond to large-scale oceanographic processes or other natural events. Overall, macrofaunal assemblages in the region remain similar to those observed prior to wastewater discharge and to natural indigenous communities characteristic of similar habitats on the southern California continental shelf. There was no evidence that wastewater discharge has caused degradation of the marine benthos in the region.

Demersal Fishes And Megabenthic Invertebrates

Speckled sanddabs continued to dominate fish assemblages surrounding the SBOO in 2010 as they have in previous years. This species occurred at all stations and accounted for 49% of the total catch for the year. Other characteristic, but less abundant species included the California lizardfish, yellowchin sculpin, English sole, roughback sculpin, hornyhead turbot, California tonguefish, and longfin sanddab. Although the composition and structure of the fish assemblages varied among stations, these differences were mostly attributable to variation in speckled sanddab, California lizardfish, white croaker, yellowchin sculpin and English sole populations. Assemblages of relatively large (megabenthic), trawl-caught invertebrates in the region were dominated by the shrimp *Crangon nigromaculata* and the sea star *Astropecten verrilli*. Variations in megabenthic community structure generally reflect changes in the abundance of these two species, as well as other common invertebrates such the sand dollar *Dendraster terminalis*, the crab *Portunus xantusii*, the brittle stars *Ophiothrix spiculata* and *Ophiura luetkeni*, the shrimp *Sicyonia ingentis*, and the squid *Doryteuthis opalescence*.

Overall, results of the 2010 trawl surveys indicated that demersal fish and megabenthic invertebrate communities in the region were unaffected by wastewater discharge. The relatively low species richness and small populations of both fish and mega-invertebrates are consistent with the shallow, sandy habitat that was surveyed. Patterns in the abundance and distribution of species were similar at stations located near the outfall and farther away, suggesting a lack of significant anthropogenic influence. Additionally, the examination of each fish for evidence of disease (e.g., tumors, fin erosion, skin lesions) or ectoparasites indicated that local fish populations remain healthy. For example, external parasites and other external abnormalities occurred in less than 0.1% of the fish collected in the South Bay outfall region during 2010. These results were consistent with findings from previous years.

Contaminants In Fish Tissues

The accumulation of contaminants in marine fishes may be due to direct exposure to contaminated water or sediments or to the ingestion of contaminated prey. Consequently, the bioaccumulation of chemical contaminants in local fishes was assessed by analyzing liver tissues from trawl-caught fishes and muscle tissues from species captured by hook and line. Results from both the liver and muscle tissue analyses indicated no evidence to suggest that contaminant loads in fishes captured in the South Bay outfall region were affected by wastewater discharge in 2010. Although several tissue samples contained metals that exceeded pre-discharge maximums, concentrations of most contaminants were generally similar to that observed prior to discharge. In addition, tissue samples that did exceed pre-discharge contaminant levels were collected from fishes that were widely distributed throughout the region and showed no pattern relative to the discharge site. Furthermore, all tissue contaminant concentrations were within the range of values reported previously for southern California fishes.

The occurrence of both metals and chlorinated hydrocarbons in fishes living around the South Bay outfall may be due to many factors, including the ubiquitous distribution of many contaminants in southern California coastal sediments. Other factors that affect the bioaccumulation and distribution of contaminants in local fishes include the different physiologies and life history traits of various species. Additionally, exposure to contaminants can vary greatly between species of fish and even among individuals of the same species depending on migration habits. For example, a fish may be exposed to contaminants in a polluted area and then migrate to a region that is less contaminated. This is of particular concern for fishes collected in the vicinity of the SBOO, as there are many other point and non-point sources that may contribute to contamination.

San Diego Regional Survey

The summer 2010 San Diego regional benthic survey covered an area ranging from offshore of Del Mar south to the USA/Mexico border. A total of 40 new, randomly selected sites were sampled at depths ranging from 9 to 433 m, and spanned four distinct depth strata as characterized by the SCB Regional Monitoring Programs (i.e., inner shelf, mid-shelf, outer shelf, upper slope).

Regional Sediments

Particle size composition of sediments at the regional stations sampled in 2010 was typical for continental shelf and upper slope benthic habitats off southern California, and consistent with results from previous surveys. These sediments consisted mainly of sands, with the percentage of silt and clay (percent fines) increasing with depth. However, several exceptions to this general pattern occurred throughout the region, particularly at outer shelf sites along the Coronado Bank, a southern rocky ridge located southwest of Point Loma at depths of 150–170 m. Sediment composition in this area is generally coarser than stations located at similar depths west of Point Loma and further to the north.

As with particle size distributions, regional patterns of sediment contamination were similar in 2010 to those observed in previous years. For example, concentrations of total nitrogen and several trace metals were found to increase with increasing percent fines. Since the percentage of these fine sediments typically increases with depth, many contaminants were detected at higher concentrations in deeper strata compared to the inner and mid-shelf areas. For example, the highest concentrations of most contaminants were found along the upper slope where some of the finest sediments were measured.

Overall, there was no evidence of widespread degradation of sediment quality at the stations surveyed during the July 2010 regional survey. ERL threshold values were exceeded in only one sample for lead (station 8023), one sample for nickel (station 8037), and two samples for DDT (stations 8012 and 8028). The total DDT measured in the sample from station 8028 was also the only exceedance of the ERM threshold at the regional sites.

Regional Macrofauna

The SCB benthos has long been considered to be composed of heterogeneous or "patchy" habitats, with the distribution of species and communities exhibiting considerable spatial variability. Results of the summer 2010 regional survey off San Diego generally support this characterization. Benthic macrofaunal assemblages in the region appeared to segregate primarily by habitat characteristics such as depth (i.e., strata) and sediment grain size, and were similar to assemblages observed during previous years.

About one-third of the benthos sampled off San Diego in 2010 was characterized by mixed sediment (~41% fines) assemblages that occurred along the mid- to outer shelf at depths of 50−123 m. These assemblages were dominated by the brittle star *Amphiodia urtica*, and correspond to the *Amphiodia* "mega-community" described previously off southern California. Deeper assemblages devoid of *A. urtica* and that were dominated instead by polychaetes (e.g., *Aphelochaeta glandaria*, *Monticellina siblina*, and *Chaetozone* sp SD5) occurred at outer shelf depths between 125−161 m where sediments were relatively coarse (~22% fines). Several nearshore assemblages were also present that are similar to those found in other shallow, sandy habitats in the SCB and as described above for the regular SBOO fixed-grid survey monitoring area. The upper slope and deepest outer shelf habitats surveyed during the year were characterized by higher percentages of fine sediments (averaging ~64–71% fines) than found at shallower shelf sites. For example, macrofaunal assemblages from the five upper slope stations that occurred at depths < 320 m clustered with those from the two deepest outer shelf stations. This shelf-slope transition assemblage lacked high abundances of *A. urtica*, but was instead dominated by polychaetes such as *Spiophanes kimballi*, *Mediomastus* sp, and *Maldane sarsi*. In contrast, macrofaunal assemblages present at the two deepest upper slope stations (depths > 420 m) where sediments averaged 71% fines comprised their own separate clade. This group was distinguished by considerably fewer species and lower abundances than elsewhere, and was represented by *M. sarsi* and the bivalve *Yoldiella nana* as the most characteristic species

Although benthic communities off San Diego vary across depth and sediment gradients, there was no evidence of disturbance during the 2010 regional survey that could be attributed to wastewater discharges, disposal sites or other point sources. Benthic macrofauna appear to be in good condition throughout the region, with 92% of the sites surveyed being classified in reference condition based on assessments using the benthic response index (BRI). This pattern is consistent with recent findings for the entire SCB mainland shelf.

Conclusions

The findings and conclusions for the ocean monitoring efforts conducted for the South Bay outfall region during calendar year 2010, as well as the summer 2010 San Diego regional benthic survey, were consistent with previous years. Overall, there were limited impacts to local receiving waters, benthic sediments, and marine invertebrate and fish communities. There was no evidence that the wastefield from the outfall reached recreational waters during the year. Although elevated bacterial levels did occur in nearshore areas, such instances were largely associated with rainfall and associated runoff during the wet season and not to shoreward transport of the wastewater plume. There were also no outfall related patterns in sediment contaminant distributions, or in differences between the various macrobenthic invertebrate and fish assemblages. The general lack of disease symptoms in local fish populations, as well as the low level of contaminants detected in fish tissues, was also indicative of a healthy marine environment. Finally, results of the regional benthic survey conducted during the year also revealed no outfall related effects, and that benthic habitats in the region remain in good condition similar to much of the southern California continental shelf.

Chapter 1
General Introduction

Chapter 1. General Introduction

INTRODUCTION

The South Bay Ocean Outfall (SBOO) discharges treated effluent to the Pacific Ocean that originates from two separate sources, including the International Wastewater Treatment Plant (IWTP) operated by the International Boundary and Water Commission (USIBWC), and the City of San Diego's South Bay Water Reclamation Plant (SBWRP). Wastewater discharge from the IWTP began on January 13, 1999 and is performed under the terms and conditions set forth in Order No. 96–50, Cease and Desist Order No. 96–52 for National Pollutant Discharge Elimination System (NPDES) Permit No. CA0108928. Discharge from the SBWRP began on May 6, 2002 and is currently performed according to the provisions set forth in Order No. R9-2006-0067 for NPDES Permit No. CA0109045. The Monitoring and Reporting Program (MRP) included in each of the above permits and orders defines the requirements for monitoring receiving waters in the South Bay coastal region, including sampling designs, compliance criteria, types of laboratory analyses, and data analysis and reporting guidelines.

All receiving waters monitoring for the South Bay outfall region with respect to the above MRPs has been performed by the City of San Diego since wastewater discharge began in 1999. The City also conducted 3½ years of pre-discharge monitoring in order to characterize background environmental conditions for the region (City of San Diego 2000a). The results of this baseline study provide background information against which post-discharge data and conditions may be compared. In addition, the City has conducted annual region-wide surveys off the coast of San Diego since 1994 either as part of regular South Bay monitoring requirements (e.g., City of San Diego 1998, 1999, 2000b, 2001–2003, 2006–2010) or as part of larger, multi-agency surveys of the entire Southern California Bight (e.g., Bergen et al. 1998, 2001, Noblet et al. 2002, Ranasinghe et al. 2003, 2007, Schiff et al. 2006). Such large-scale surveys are useful in characterizing the ecological health of diverse coastal areas and may help to identify and distinguish reference sites from those impacted by wastewater or stormwater discharges, urban runoff, or other sources of contamination.

Finally, the City and USIBWC also contract with Ocean Imaging of Solana Beach, California to conduct a remote sensing program for the San Diego/Tijuana region as part of the ocean monitoring programs for the Point Loma and South Bay outfall areas. Imagery from satellite data and aerial sensors produce a synoptic picture of surface water clarity that is not possible using shipboard sampling alone. However, a major limitation of aerial and satellite images is that they only provide information about surface or near-surface waters (~0–15 m) without providing direct data regarding the movement, color, or clarity of deeper waters. In spite of these limitations, one objective of this project is to ascertain relationships between the various types of imagery and data collected in the field. With public health issues being a paramount concern of ocean monitoring programs, any information that helps to provide a clearer and more complete picture of water conditions is beneficial to the general public as well as to program managers and researchers. Having access to a large-scale overview of surface waters within a few hours of image collection also has the potential to bring the monitoring program closer to real-time diagnoses of possible contamination, and adds predictability to the impact that natural events such as storms and heavy rains may have on shoreline water quality. Results from the remote sensing program for calendar year 2010 are summarized in Svejkovsky (2011).

This report presents the results of all receiving waters monitoring activities conducted as part of the South Bay ocean monitoring program in 2010. Included are results from all fixed stations that comprise a grid surrounding the South Bay outfall, as well as results from the summer 2010 regional benthic survey of randomly selected sites off San Diego. The results of the remote sensing surveys conducted during the year as reported by Svejkovsky (2011) are also considered and integrated into interpretations of oceanographic and water quality data (e.g., fecal indicator bacteria, total suspended solids, oil and grease). Comparisons are also made herein to conditions present during previous years in order to evaluate changes that may be related to wastewater discharge and transport or to other anthropogenic or natural factors. The major components of the monitoring program are covered in the following chapters: Oceanographic Conditions, Water Quality, Sediment Conditions, Macrobenthic Communities, Demersal Fishes and Megabenthic Invertebrates, Bioaccumulation of Contaminants in Fish Tissues, Regional Sediment Conditions, and Regional Macrobenthic Communities. Some general background information and procedures for the regular fixed-grid monitoring and regional surveys and associated sampling designs are given below and in subsequent chapters and appendices.

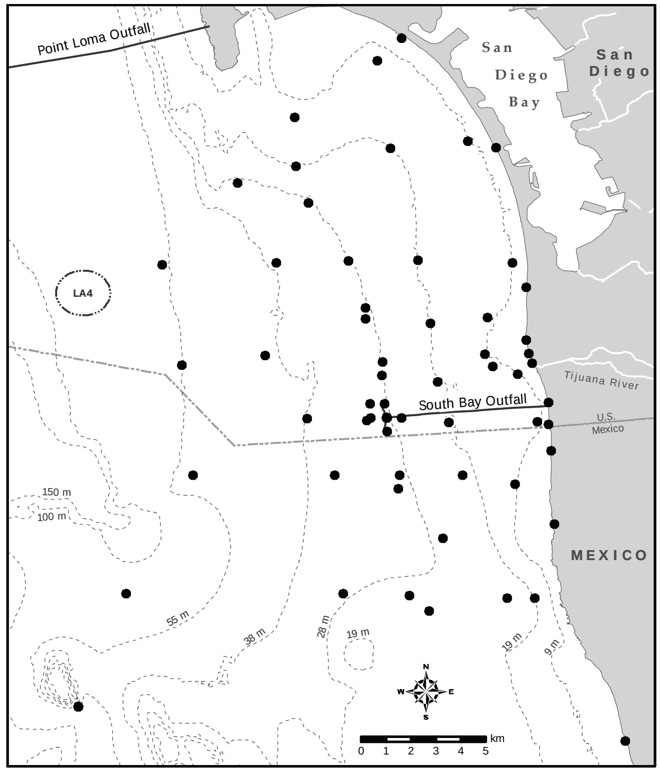

Figure 1.1
Receiving waters monitoring stations for the South Bay Ocean Outfall Monitoring Program.

Regular Fixed-Grid Monitoring

The SBOO is located just north of the border between the United States and Mexico. The outfall terminates approximately 5.6 km offshore at a depth of about 27 m. Unlike other southern California ocean outfall structures that are located on the surface of the seabed, the pipeline first begins as a tunnel on land and then continues under the seabed to a distance of about 4.3 km offshore. From there it connects to a vertical riser assembly that conveys effluent to a pipeline buried just beneath the surface of the seabed. This subsurface pipeline then splits into a Y-shaped multiport diffuser system (i.e., wye), with the two diffuser legs extending an additional 0.6 km to the north and south. The outfall was originally designed to discharge wastewater via a total of 165 diffuser ports and risers, which included one riser located at the center of the wye and 82 others spaced along each diffuser leg. However, consistent low flows have required closure of all ports along the northern diffuser leg and many along the southern diffuser as well since discharge began in order to maintain sufficient back pressure within the drop shaft so that the outfall can operate in accordance with the theoretical model. Consequently, wastewater discharge has been generally limited to the distal end of the southern diffuser leg, with the exception of a few intermediate points at or near the center of the diffuser legs.

The regular sampling area for the South Bay outfall region extends from the tip of Point Loma southward to Playa Blanca, northern Baja California (Mexico), and from the shoreline seaward to a depth of about 61 m (Figure 1.1). The offshore monitoring stations are arranged in a grid that spans the terminus of the outfall, with each site being monitored in accordance with NPDES permit requirements. Sampling at these fixed (core) stations includes monthly seawater measurements of physical, chemical, and bacteriological parameters in order to document water quality conditions in the area. Benthic sediment samples are collected semiannually to monitor macrobenthic invertebrate communities and sediment conditions. Trawl surveys are performed quarterly to monitor communities of demersal fish and large, bottom-dwelling invertebrates (megabenthos). Additionally, analyses of fish tissues are performed semiannually to assess the bioaccumulation of chemical constituents that may have ecological or human health implications.

Random Sample Regional Surveys

In addition to the core fixed-station sampling, the City typically conducts a summer benthic survey of sites distributed throughout the entire San Diego region as part of the monitoring requirements for the South Bay program. These surveys are based on an array of stations that are randomly selected by the United States Environmental Protection Agency (USEPA) using the probability-based Environmental Monitoring and Assessment Program (EMAP) design. Surveys conducted in 1994, 1998, 2003, and 2008 involved other major southern California dischargers, were broader in scope, and included sampling sites representing the entire Southern California Bight (SCB) from Cabo Colonet, Mexico to Point Conception, USA. These surveys included the Southern California Bight Pilot Project (SCBPP) in 1994, and the 1998, 2003 and 2008 SCB Regional Monitoring Programs (i.e., Bight'98, Bight'03, and Bight'08, respectively). Results of the 1994–2003 regional programs are available in Bergen et al. (1998, 2001), Noblet et al. (2002), Ranasinghe et al. (2003, 2007), and Schiff et al. (2006), whereas analysis of data for Bight'08 is currently underway. A separate regional survey for San Diego was not conducted in 2004 in order to conduct the first phase of a "sediment mapping" study pursuant to an agreement with the San Diego Regional Water Quality Control Board (RWQCB) and USEPA (see Stebbins et al. 2004, City of San Diego 2005).

The same randomized sampling design was used to select 40 new stations per year for each of the summer surveys restricted to the San Diego region in 1995–1997 and 1999–2002. Beginning in 2005,

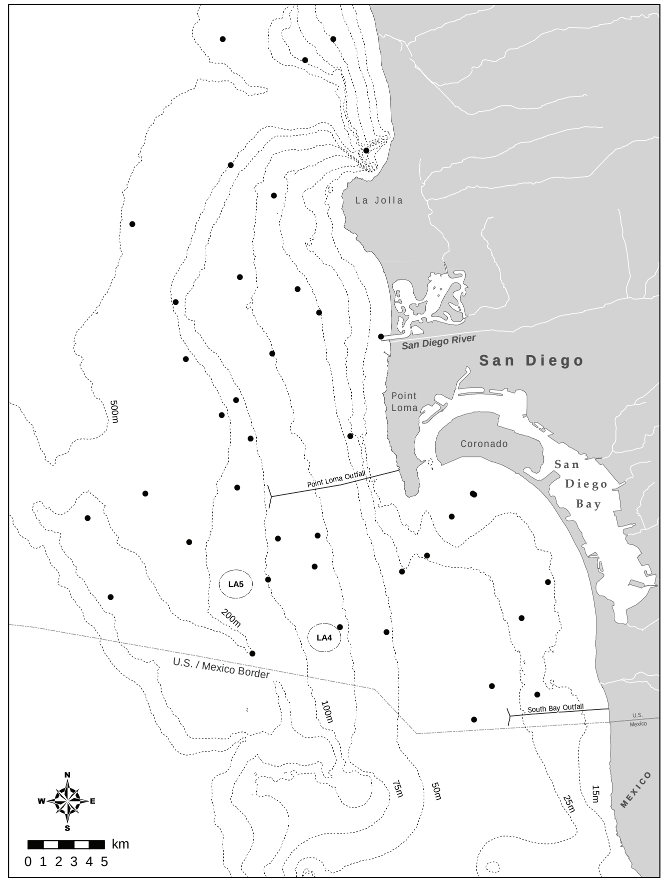

Figure 1.2
Regional benthic survey stations for the South Bay Ocean Outfall Monitoring Program during 2010.

however, an agreement was reached between the City, RWQCB and USEPA to revisit the same sites successfully sampled 10 years earlier in order to facilitate comparisons of long-term changes in benthic conditions. Unsuccessful sampling during all of these surveys was typically due to the presence of rocky substrates that made it impossible to collect benthic grab samples. Thus, 36 sites were revisited in 2005, 34 sites in 2006, and 39 sites in 2007. As indicated above, no separate survey for the San Diego region was conducted in 2008 due to participation in Bight'08. In 2009, sampling was conducted at the 34 sites originally sampled in 1999 as well as six additional new sites located further offshore in waters deeper than 200 m (see City of San Diego 2010). These latter six stations were added to provide information on deeper continental slope habitats off San Diego. The summer 2010 regional survey reported herein involved sampling 40 new randomly selected stations (Figure 1.2) provided by the USEPA and covering an area ranging from Del Mar in northern San Diego County south to the USA/Mexico border, and extending offshore from depths of about 9 to 433 m. These stations included 33 sites located at continental shelf depths < 200 m and 7 upper slope stations located at depths ≥ 200 m.

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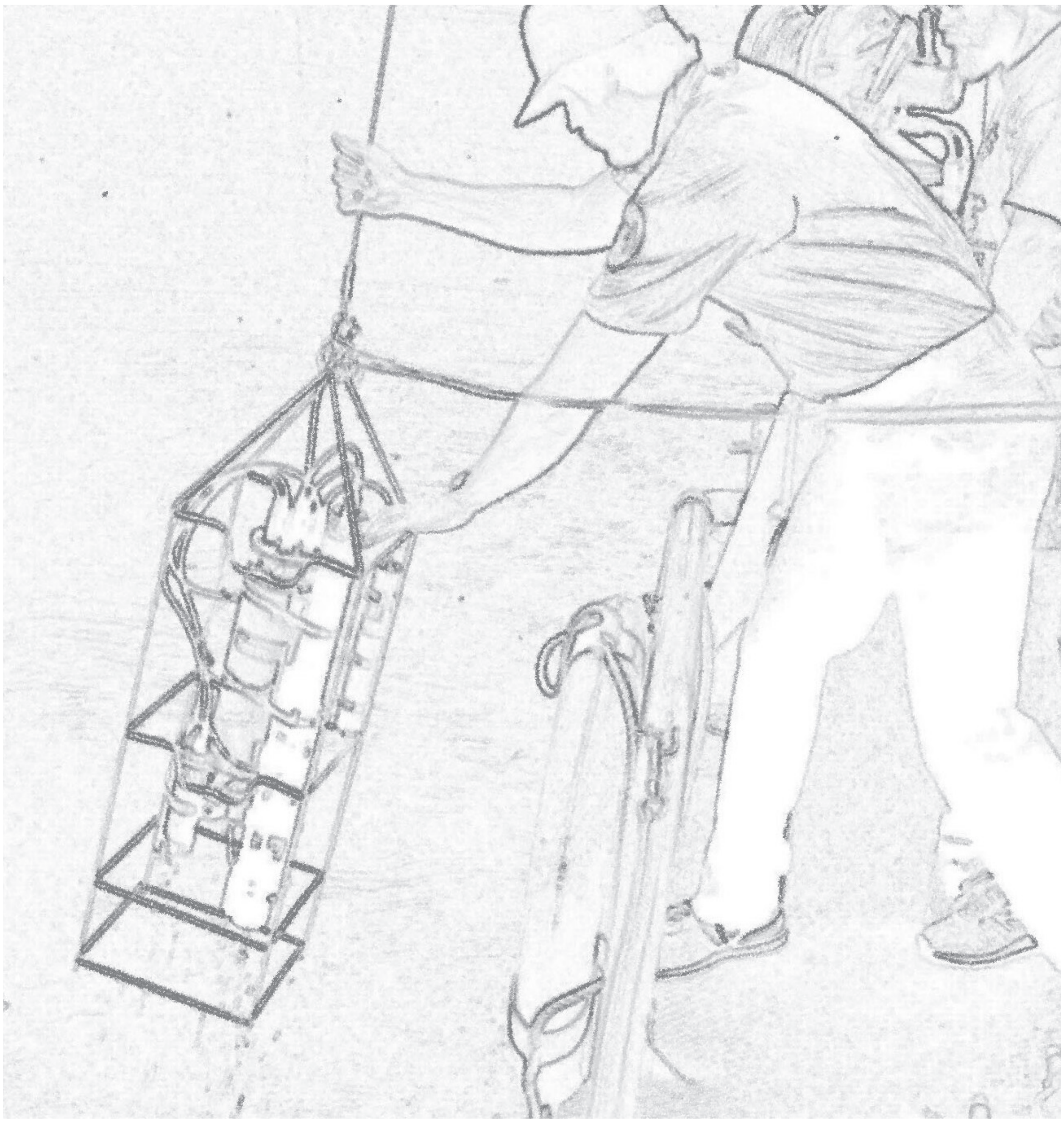
Chapter 2
Oceanographic Conditions



Chapter 2. Oceanographic Conditions

INTRODUCTION

The City of San Diego monitors oceanographic conditions in the region surrounding the South Bay Ocean Outfall (SBOO) to assist in evaluating possible impacts of wastewater discharge on the marine environment. Measurements of water temperature, salinity, density, light transmittance (transmissivity), dissolved oxygen and pH, in conjunction with biological indicators such as chlorophyll concentrations, are important indicators of biological and physical oceanographic processes (Skirrow 1975) that can impact marine life within a region (Mann 1982, Mann and Lazier 1991). In addition, because the fate of wastewater discharged into marine waters is determined not only by the geometry of an ocean outfall's diffuser structure and the rate of discharge, but also by oceanographic factors that govern water mass movement (e.g., horizontal and vertical mixing of the water column, current patterns), evaluations of physical parameters that influence the mixing potential of the water column are important components of ocean monitoring programs (Bowden 1975, Pickard and Emery 1990). For example, the degree of vertical mixing or stratification, and the depth at which the water column is stratified, indicates the likelihood and depth of wastewater plume trapping.

In relatively nearshore waters such as the SBOO monitoring region, oceanographic conditions are strongly influenced by seasonal changes (Bowden 1975, Skirrow 1975, Pickard and Emery 1990). Southern California weather can generally be classified into a wet, winter season (typically December through February) and a dry, summer season (typically July through September) (NOAA/NWS 2010), and differences between these seasons affect oceanographic conditions such as water column stratification and current patterns. For example, storm activity during southern California winters brings higher winds, rain, and waves which often contribute to the formation of a well-mixed, relatively homogenous or non-stratified water column (Jackson 1986). The chance that wastewater plumes from sources such as the SBOO may surface is highest during such times when the water column is well mixed and there is little, if any, stratification. These conditions often extend into spring as the frequency of storms decreases and the transition from wet to dry conditions begins. In late spring the increasing elevation of the sun and longer days begin to warm surface waters resulting in increased surface evaporation (Jackson 1986). Mixing conditions also diminish with decreasing storm activity, and seasonal thermoclines and pycnoclines become re-established. Once the water column becomes stratified again by late spring, minimal mixing conditions typically remain throughout the summer and early fall months. In the fall, cooler temperatures, along with increases in stormy weather, begin to cause the return of well-mixed water column conditions.

Understanding changes in oceanographic conditions due to natural processes like the seasonal patterns described above is important since they can affect the transport and distribution of wastewater, storm water and other types of turbidity (e.g., sediment, contaminant) plumes. In the South Bay outfall region these include plumes associated with tidal exchange from San Diego Bay, outflows from the Tijuana River in U.S. waters and Los Buenos Creek in northern Baja California, storm water discharges, and runoff from local watersheds. For example, flows from San Diego Bay and the Tijuana River are fed by 1075 km^2 and 4483 km^2 of watershed, respectively, and can contribute significantly to nearshore turbidity, sediment deposition, and bacterial contamination (see Largier et al. 2004, Terrill et al. 2009). Overall, these different sources can affect water quality conditions both individually and synergistically.

This chapter describes the oceanographic conditions that occurred in the South Bay outfall region during 2010. The main objectives are to: (1) describe deviations from expected oceanographic patterns,

(2) assess possible influence of the SBOO wastewater discharge relative to other input sources, (3) determine the extent to which water mass movement or water column mixing affects the dispersion/dilution potential for discharged materials, and (4) demonstrate the influence of natural events such as storms or El Niño/ La Niña oscillations. The results of remote sensing observations (e.g., aerial and satellite imagery) may also provide useful information on the horizontal transport of surface waters (Pickard and Emery 1990, Svejkovsky 2011). Thus, this chapter combines measurements of physical oceanographic parameters with assessments of remote sensing data to provide further insight into the transport potential in coastal waters surrounding the SBOO discharge site. The results reported herein are also referred to in subsequent chapters to explain patterns of indicator bacteria distributions (see Chapter 3) or other changes in the local marine environment (see Chapters 4–7).

Materials and Methods

Field Sampling

Oceanographic measurements were collected at fixed sampling sites located in a grid pattern encompassing an area of ~300 km^2 surrounding the SBOO (Figure 2.1). These forty offshore stations (designated I1–I40) are located ~3.4–14.6 km offshore along or adjacent to the 9, 19, 28, 38 and 55-m depth contours. The stations were sampled monthly, usually over a 3-day period; the only exception was during April 2010 when offshore water quality sampling was not conducted due to a Bight'08 resource exchange. Sites were grouped together during each sampling period as follows: "North Water Quality" stations I28–I38 ($n=11$); "Mid Water Quality" stations I12, I14–I19, I22–I27, I39, I40 ($n=15$); "South Water Quality" stations I1–I11, I13, I20, I21 ($n=14$). See Appendix A.1 for the actual dates samples were collected during 2010.

Data for the various oceanographic parameters were collected using a SeaBird conductivity, temperature, and depth instrument (CTD). The CTD was lowered through the water column at each station to collect continuous measurements of water temperature, salinity, density, pH, transmissivity (a proxy for water clarity), chlorophyll *a* (a proxy for the presence of phytoplankton), and dissolved oxygen (DO). Profiles of each parameter were then constructed for each station by averaging the data values recorded over 1-m depth intervals. This data reduction ensured that physical measurements used in subsequent analyses could correspond to discrete sampling depths for indicator bacteria (see Chapter 3). Visual observations of weather and water conditions were recorded just prior to each CTD cast.

Remote Sensing – Aerial and Satellite Imagery

Coastal monitoring of the SBOO region during 2010 included remote imaging analyses performed by Ocean Imaging (OI) of Solana Beach, CA. All satellite and aerial imaging data collected during the year are made available for review and download from OI's website (Ocean Imaging 2011), while a separate annual report to summarize these data

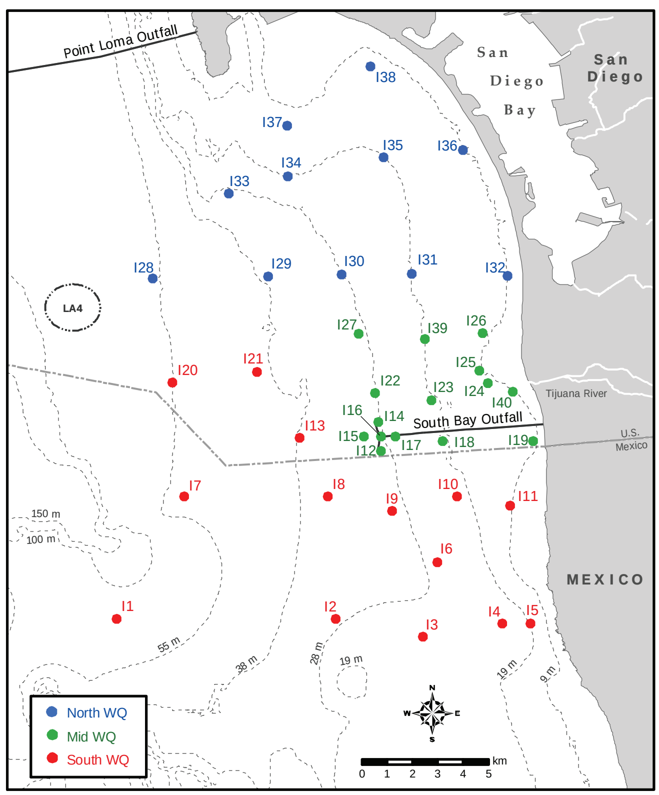


Figure 2.1
Water quality (WQ) monitoring stations where CTD casts are taken, South Bay Ocean Outfall Monitoring Program.

is also produced (Svejkovsky 2011). This chapter includes examples of Thematic Mapper TM5 thermal satellite imagery. Examples of multispectral color imagery from OI's DMSC-MKII aerial sensor and thermal infrared (IR) imagery from a Jenoptik thermal imager integrated into the system are also included. Additionally, color images from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite are included in the Water Quality chapter (see Chapter 3). These technologies differ in terms of their resolution, frequency of collection, depth of penetration, and detection capabilities as described in the "Technology Overview" section of Svejkovsky (2011).

Data Treatment

The various water column parameters measured in 2010 were summarized as monthly means of surface (top 2 m) and bottom (bottom 2 m) waters over all stations located along each of the 9, 19, 28, 38 and 55-m depth contours to provide an overview of trends throughout the entire year. For spatial analysis, 3-dimensional graphical views were created for each month using Interactive Geographical Ocean Data System software (IGODS), which uses a linear interpolation between stations and with depth at each site. In most cases, inclusion of these analyses was limited herein to four monthly surveys representative of the winter (February), spring (May), summer (August), and fall (November) seasons. These surveys were selected because they correspond to the quarterly water quality surveys typically conducted as part of the coordinated Point Loma Ocean Outfall (PLOO) and Central Bight Regional monitoring efforts. Additional analysis included vertical profiles using the 1-m binned data for each parameter from the same surveys listed above, but limited to a subset of seven stations along the 28-m depth contour (i.e., stations I3, I9, I12, I14, I16, I22, I27). These profiles were created to provide a more detailed view of data depicted in the IGODS graphics. Finally, a time series of anomalies for each parameter was created to evaluate significant oceanographic events in the region. Anomalies were calculated by subtracting the monthly means for each year between 1995–2010 from the mean of all 16 years combined. These mean values were calculated using data from all of the 28-m depth contour stations, with all water column depths combined.

Results

Oceanographic Conditions in 2010

Water temperature and density

Seawater density is a product of temperature, salinity and pressure. In the shallower coastal waters of southern California, density is influenced primarily by temperature differences since salinity is relatively uniform (Bowden 1975, Jackson 1986, Pickard and Emery 1990). This relationship was evident in the South Bay outfall region during 2010 as indicated by the strong correlation between temperature and density (Pearson correlation coefficient $r(11,119) = 0.99$, $p < 0.001$; Figure 2.2). However, some deviations occurred as a result of fresh water runoff into the survey area during February, March, and December; each were months with relatively high levels of rainfall (see Table 3.1 for rainfall levels). Because of this strong relationship, changes in density typically mirror those in water temperatures, and results discussed below for temperature can be assumed to also apply to density.

Mean surface temperatures across the entire SBOO region ranged from 12.9°C in December to 19.1°C in October, while bottom temperatures averaged from 10.2°C in June to 16.4°C in October in 2010 (Table 2.1). Overall, these surface and bottom water temperatures were lower than during 2009. For example, surface temperatures peaked in September 2009 at about 21ºC (City of San Diego 2010). As expected, the lowest temperatures of the year occurred at bottom depths during the spring and summer (Table 2.1, Figure 2.3, Figure 2.4). These colder bottom waters, which likely reflect coastal upwelling, entered the SBOO region as early as February at northern offshore stations (Figure 2.4A). Temperatures also varied as expected by season, with the water column ranging

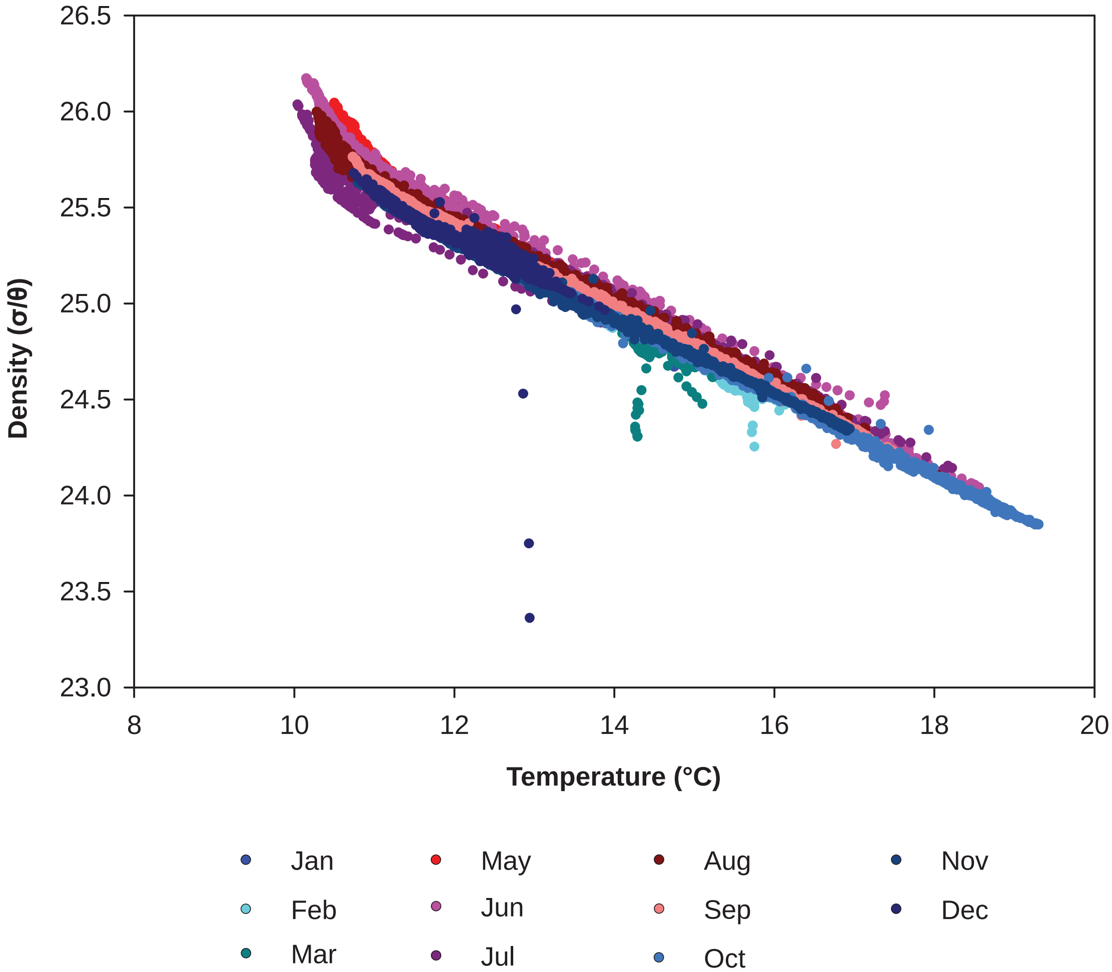


Figure 2.2
Scatterplot of temperature and density for SBOO stations sampled in 2010.

from mixed in the winter, to highly stratified in late summer/early fall, to less stratified in late fall. However, the water column was not as well-mixed during January and February 2010 as it has been in previous years, with average temperatures differing between surface and bottom depths by as much as 3ºC. Since temperature is the main contributor to water column stratification in southern California (Dailey et al. 1993, Largier et al. 2004), differences between surface and bottom temperatures were important to limiting the surfacing potential of the wastewater plume during certain times of the year. Results from remote sensing observations and discrete bacteriological samples indicated that the plume surfaced during January, February, March and December when the water column was more mixed, but was never detected in surface waters between April and November, when the water column was stratified enough to keep the plume submerged (e.g., Figure 2.5; see also Svejkovsky 2011).

Salinity

Average salinities for surface waters in the SBOO region ranged from a low of 33.18 psu in December to a high of 33.57 psu in June and July, and from 33.36 psu in November to 34.00 psu in June at bottom depths (Table 2.1). Relatively low salinity values (e.g., < 33.50 psu) were observed at the surface across parts of the region during the rainy months of January, February, March and December, often with the lowest values at stations located near the mouth of the Tijuana River or the entrance to San Diego Bay (e.g., Figure 2.6A). In contrast, high salinity values (e.g., > 33.65 psu) extended across most of the region at bottom depths in the spring and summer and correspond to the lower temperatures found at bottom depths as described

Table 2.1

Summary of temperature, salinity, dissolved oxygen, pH, transmissivity, and chlorophyll *a* for surface and bottom waters in the SBOO region during 2010. Values are expressed as means for each month pooled over all stations along each depth contour.

Depth	Contour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (ºC)													
9-m	Surface	14.71	15.61	13.21	ns	15.00	17.65	14.84	15.39	16.26	18.19	15.61	13.05
	Bottom	14.60	14.85	12.72	ns	12.29	15.85	11.49	11.90	15.30	16.41	14.78	12.69
19-m	Surface	14.86	15.60	13.67	ns	15.96	17.31	14.99	15.48	16.48	18.38	15.81	12.88
	Bottom	14.65	14.16	12.31	ns	11.40	11.48	10.65	10.75	12.66	14.59	13.09	12.19
28-m	Surface	14.91	15.57	13.76	ns	15.79	16.81	15.84	16.36	16.80	18.72	16.19	12.97
	Bottom	14.74	13.81	11.34	ns	10.94	10.73	10.41	10.51	11.91	13.28	12.36	11.93
38-m	Surface	15.24	15.72	14.48	ns	15.96	16.38	15.52	16.42	17.10	18.89	16.58	13.09
	Bottom	14.72	12.86	11.05	ns	10.77	10.38	10.29	10.46	11.45	12.39	11.94	11.38
55-m	Surface	15.26	15.54	14.78	ns	15.24	16.86	17.80	16.37	17.01	19.08	16.64	13.38
	Bottom	13.94	12.58	10.91	ns	10.61	10.22	10.27	10.32	10.91	11.20	11.08	11.04
Salinity (psu)													
9-m	Surface	33.40	33.32	33.26	ns	33.50	33.52	33.54	33.50	33.46	33.47	33.40	33.41
	Bottom	33.40	33.38	33.44	ns	33.54	33.57	33.50	33.54	33.46	33.42	33.39	33.42
19-m	Surface	33.39	33.36	33.40	ns	33.51	33.50	33.55	33.51	33.44	33.47	33.41	33.41
	Bottom	33.40	33.41	33.51	ns	33.62	33.66	33.54	33.61	33.47	33.38	33.36	33.44
28-m	Surface	33.37	33.36	33.38	ns	33.52	33.51	33.54	33.52	33.47	33.51	33.42	33.18
	Bottom	33.39	33.42	33.63	ns	33.73	33.70	33.58	33.66	33.49	33.39	33.36	33.41
38-m	Surface	33.41	33.34	33.36	ns	33.50	33.53	33.53	33.54	33.46	33.52	33.45	33.37
	Bottom	33.39	33.46	33.69	ns	33.79	33.81	33.65	33.77	33.49	33.40	33.39	33.44
55-m	Surface	33.43	33.39	33.35	ns	33.49	33.57	33.57	33.44	33.46	33.54	33.44	33.39
	Bottom	33.40	33.49	33.71	ns	33.90	34.00	33.65	33.80	33.57	33.45	33.43	33.48
Dissolved Oxygen (mg/L)													
9-m	Surface	7.98	7.97	7.35	ns	8.21	9.95	7.55	9.91	9.22	7.85	8.49	8.51
	Bottom	7.76	7.33	6.34	ns	5.39	7.94	5.56	6.78	8.37	7.58	7.37	7.66
19-m	Surface	7.88	7.94	7.75	ns	8.87	9.17	7.69	10.34	9.34	8.04	8.74	8.50
	Bottom	7.53	6.77	5.82	ns	3.61	5.13	5.18	4.56	6.19	7.22	6.16	7.21
28-m	Surface	7.54	8.07	8.04	ns	8.68	8.50	7.97	10.58	8.77	7.77	8.41	8.61
	Bottom	7.31	6.45	4.78	ns	2.94	3.99	5.05	4.31	4.91	6.61	6.01	6.45
38-m	Surface	7.56	8.13	8.73	ns	8.82	8.66	7.94	10.23	8.83	7.63	8.48	9.36
	Bottom	7.18	5.72	4.43	ns	2.84	3.42	4.56	3.46	4.92	6.03	5.53	5.70
55-m	Surface	7.35	8.13	9.00	ns	8.74	8.28	8.28	8.75	8.55	7.54	8.27	8.72
	Bottom	6.22	5.49	4.35	ns	2.73	2.45	4.63	3.70	4.28	5.62	5.98	5.53

ns = not sampled (see text)

Table 2.1 *continued*

Depth	Contour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pH													
9-m	Surface	8.19	8.15	8.05	ns	8.22	8.34	8.02	8.24	8.25	8.26	8.15	8.17
	Bottom	8.18	8.11	8.00	ns	7.94	8.20	7.87	8.05	8.18	8.20	8.08	8.09
19-m	Surface	8.19	8.17	8.10	ns	8.31	8.27	8.03	8.27	8.27	8.26	8.20	8.16
	Bottom	8.17	8.07	7.98	ns	7.79	7.91	7.79	7.85	8.00	8.15	7.96	8.02
28-m	Surface	8.17	8.17	8.14	ns	8.28	8.20	8.08	8.29	8.25	8.26	8.19	8.18
	Bottom	8.15	8.05	7.90	ns	7.74	7.80	7.77	7.81	7.89	8.08	7.92	7.95
38-m	Surface	8.17	8.20	8.23	ns	8.28	8.21	8.10	8.29	8.26	8.24	8.20	8.20
	Bottom	8.14	7.99	7.87	ns	7.73	7.75	7.75	7.76	7.91	8.01	7.88	7.89
55-m	Surface	8.10	8.17	8.22	ns	8.23	8.18	8.18	8.20	8.23	8.23	8.18	8.16
	Bottom	8.03	7.96	7.85	ns	7.70	7.67	7.93	7.76	7.83	7.95	7.89	7.86
Transmissivity (%)													
9-m	Surface	71.40	58.60	55.75	ns	67.55	63.75	71.25	67.25	69.80	80.25	77.20	74.05
	Bottom	70.76	46.22	58.35	ns	66.52	74.23	73.37	63.18	76.63	71.64	74.33	72.09
19-m	Surface	79.50	73.72	71.33	ns	74.22	73.94	77.06	69.89	75.28	83.22	83.06	78.39
	Bottom	77.00	63.65	75.00	ns	67.83	75.65	85.21	79.75	80.35	76.46	77.39	74.29
28-m	Surface	82.15	77.88	78.46	ns	82.04	81.85	78.73	71.81	80.77	89.04	86.42	79.23
	Bottom	78.76	74.43	82.07	ns	75.00	84.78	89.48	85.75	83.60	81.29	85.45	83.08
38-m	Surface	87.00	83.38	79.63	ns	85.38	75.13	81.63	71.63	82.75	90.00	87.75	77.75
	Bottom	82.58	77.38	83.25	ns	74.70	89.00	89.83	82.58	87.62	86.27	87.58	81.40
55-m	Surface	88.50	85.63	77.13	ns	85.63	83.38	82.88	81.88	85.50	90.00	88.50	81.38
	Bottom	86.93	85.43	85.86	ns	86.57	88.91	89.57	88.36	89.00	90.79	90.64	89.14
Chlorophyll *a* (µg/L)													
9-m	Surface	8.94	4.47	7.49	ns	12.87	29.72	5.58	23.07	25.00	8.03	8.40	7.26
	Bottom	10.70	7.21	8.22	ns	23.34	10.90	7.38	40.63	11.73	9.32	8.83	7.61
19-m	Surface	3.32	3.03	6.16	ns	6.25	13.15	5.53	16.33	12.69	8.40	3.93	8.05
	Bottom	4.71	3.93	5.13	ns	30.24	18.93	3.40	15.29	6.91	7.20	5.61	11.24
28-m	Surface	2.60	2.45	3.77	ns	2.61	3.79	4.55	9.86	6.99	3.19	2.05	6.57
	Bottom	4.40	3.38	1.82	ns	24.70	9.44	1.56	6.38	5.61	5.43	6.28	7.91
38-m	Surface	2.19	1.41	3.20	ns	1.42	6.98	3.00	8.43	2.73	2.02	1.45	11.93
	Bottom	3.70	1.46	1.36	ns	31.13	1.81	0.99	9.63	3.39	3.32	2.58	5.40
55-m	Surface	2.15	1.82	7.65	ns	2.35	5.43	2.31	6.96	3.17	2.14	1.58	12.08
	Bottom	2.29	1.17	0.69	ns	4.62	0.77	0.83	0.58	1.75	1.63	1.59	2.41

ns = not sampled (see text)

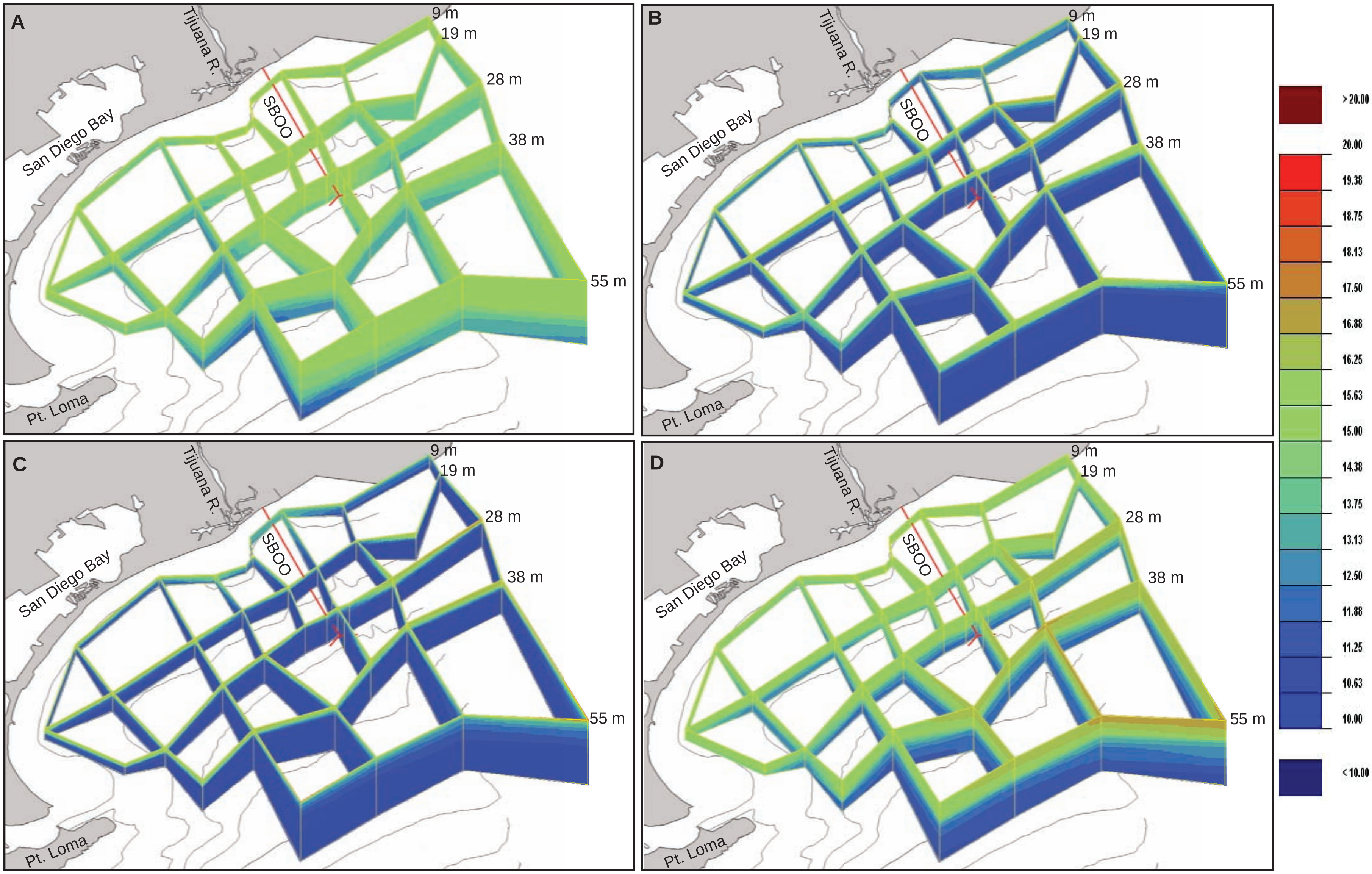


Figure 2.3

Ocean temperatures recorded in 2010 for the SBOO region during (A) February, (B) May, (C) August, and (D) November. Data are collected over three days during each of these monthly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.

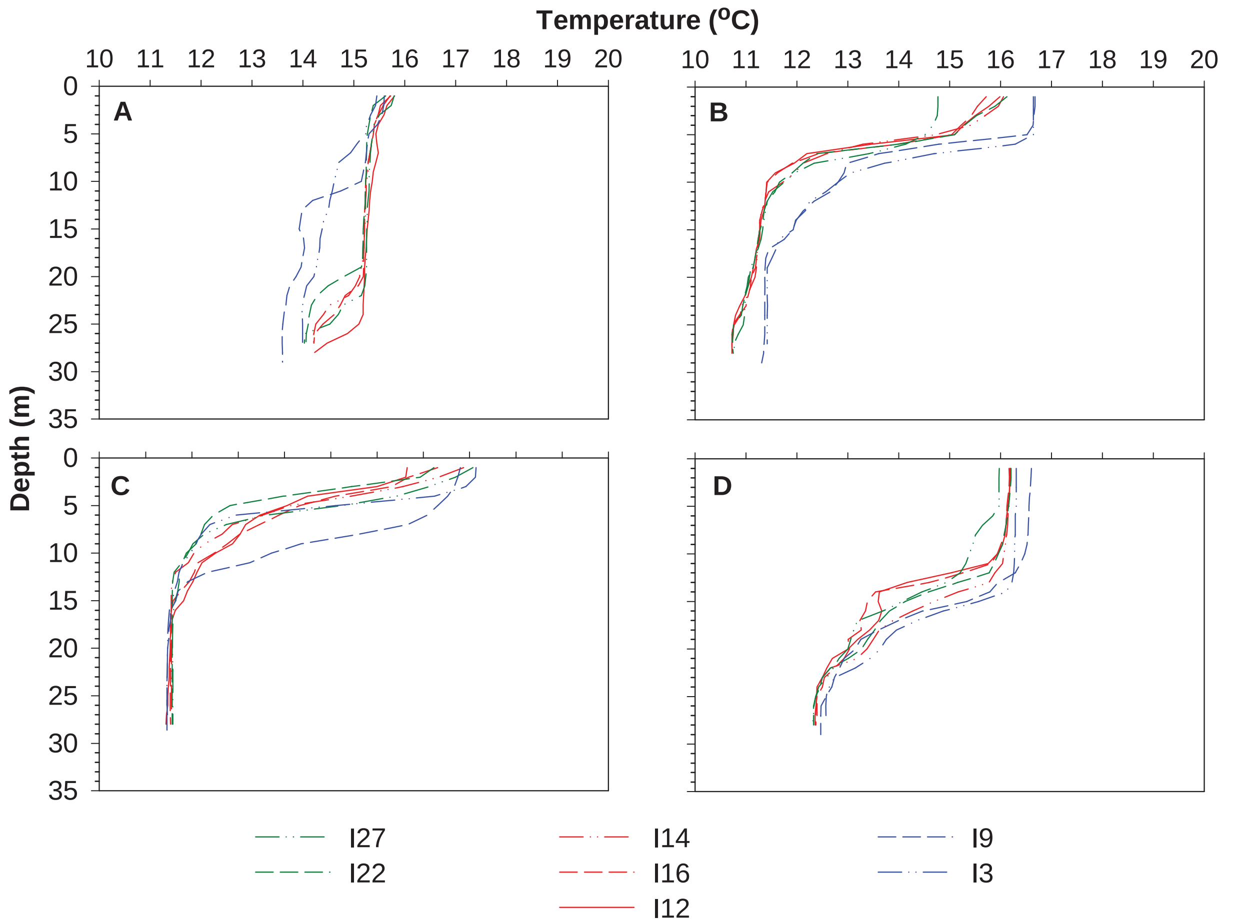


Figure 2.4
Vertical profiles of ocean temperature for SBOO stations during (A) February, (B) May, (C) August, and (D) November 2010.

above (e.g., Figure 2.6). Taken together, these factors are indicative of coastal upwelling that is typical for this time of year (Jackson 1986).

There was some evidence of another region-wide phenomenon in the SBOO region during the spring, summer, and fall of 2010, when a thin layer of salinity values below about 33.40 psu occurred at sub-surface depths between ~10 and 20 m (e.g., Figure 2.6, Figure 2.7, Appendix A.2). It seems unlikely that this sub-surface salinity minimum (SSM) could be due to SBOO discharge for several reasons. First, no evidence has ever been reported of the plume extending simultaneously throughout the region in so many directions. Instead, results from remote sensing observations (Svejkovsky 2010) and other oceanographic studies (e.g., Terrill et al. 2009) have demonstrated that the SBOO plume disperses in one specific direction at any given time (e.g., south, southeast, north). Second, seawater samples collected at the same depths and times did not contain elevated levels of indicator bacteria (see Chapter 3). Third, similar SSMs have been reported previously off San Diego and elsewhere in southern California, including: (a) the Point Loma monitoring region during the summer and fall of 2009 (City of San Diego 2010); (b) coastal waters off Orange County, California for many years (e.g., OCSD 1999); (c) coastal waters extending as far north as Ventura, California (OCSD 2009). Further investigations are required to determine the possible source(s) of this phenomenon.

When compared to the region-wide phenomenon described above, salinity levels were found to be even lower (i.e., <33.30 psu) at a few stations close to the SBOO at various depths during almost every survey. For example, salinity values were as low as 33.29 stations I12 and I9 during February (Figure 2.7A), when other stations never had

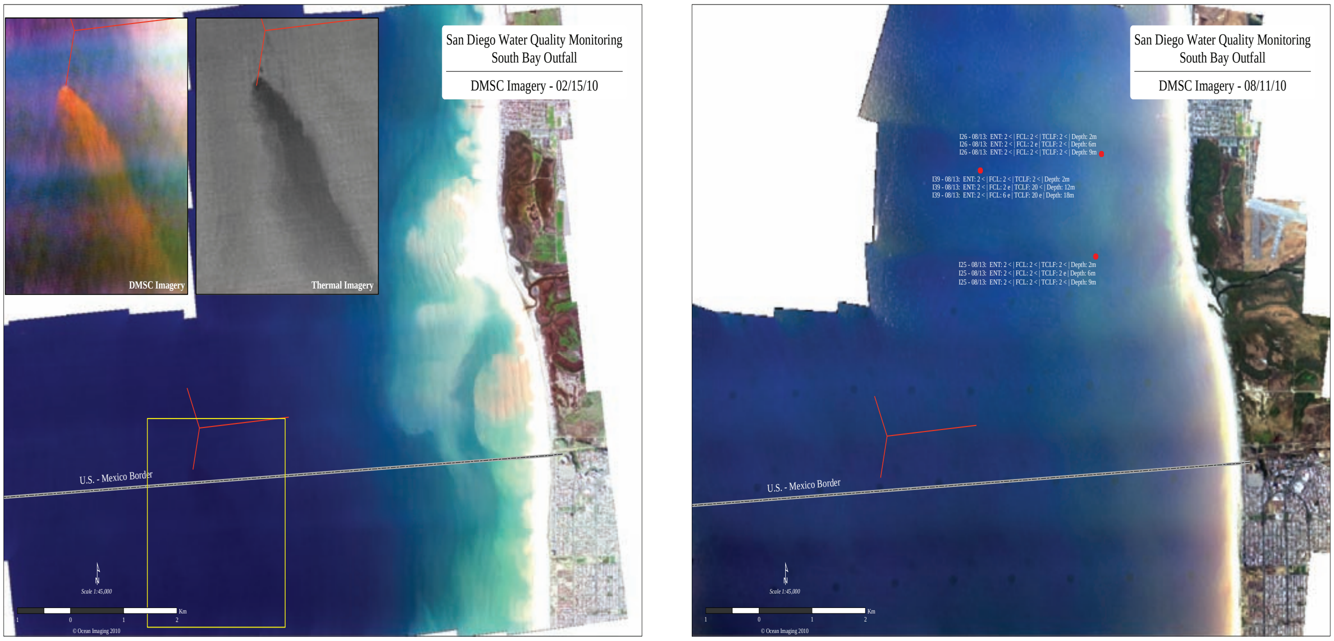


Figure 2.5
DMSC images of the SBOO and coastal region acquired on February 15, 2010, demonstrating when the SBOO plume reaches the surface (left), and on August 11, 2010, demonstrating when the SBOO plume is submerged under the thermocline (right) (see text; images from Ocean Imaging 2011).

salinity values below 33.35 psu (Figure 2.6A). Further, salinity values reached as low as 33.27 psu at stations I12, I14, and I16 during November (Figure 2.7D), which was about 0.12 psu less than other stations along the 28-m depth contour at that time (Figure 2.6D).

Dissolved oxygen and pH

Dissolved oxygen (DO) concentrations averaged from 7.35 to 10.58 mg/L in surface waters and from 2.45 to 8.37 mg/L in bottom waters across the South Bay outfall region in 2010, while mean pH values ranged from 8.02 to 8.29 in surface waters and from 7.67 to 8.20 in bottom waters (Table 2.1). Changes in pH were closely linked to changes in DO since both parameters tend to reflect the loss or gain of carbon dioxide associated with biological activity in shallow waters (Skirrow 1975).

Stratification of the water column followed normal seasonal patterns for DO with the greatest variations and maximum stratification occurring during the spring and summer (e.g., Appendices A.3, A.4). Low concentrations of DO at mid- and deeper depths during spring and summer months likely result from cold, saline and oxygen poor ocean water moving inshore during periods of coastal upwelling as indicated above for temperature and salinity. In contrast, very high DO values just below surface waters (i.e., at the thermocline) were likely the result of phytoplankton blooms as these high DO values correspond with high chlorophyll values at the same depths during the same surveys. Deviations of DO concentrations at stations close to the outfall (i.e., stations I12 and I16) were apparent only during November (Appendix A.4D). These variations were slight (<1.2 mg/L) and highly localized. The variations were so small, in fact, that they were not apparent in the 3-D graphics (Appendix A.3D).

Transmissivity

Transmissivity appeared to be within historical ranges in the SBOO region during 2010 with average values of 56–90% on the surface and 46–91% in bottom waters (Table 2.1). Water clarity was consistently greater at the offshore monitoring sites than in nearshore waters by as much as 27% at the surface and 39% at the bottom. Reductions in water clarity that occurred at various depths across the region (including stations nearest the outfall) throughout the year tended to co-occur with

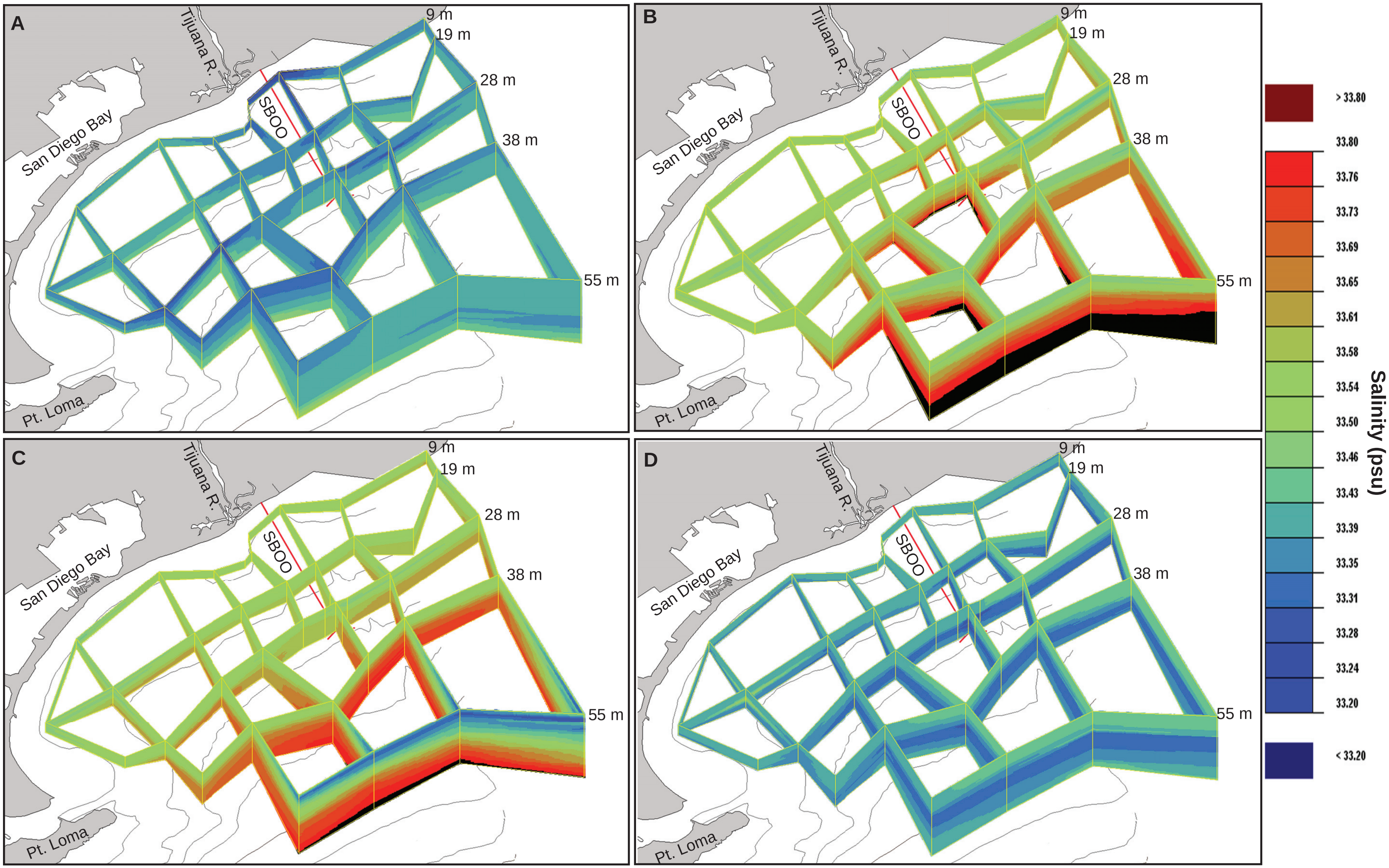


Figure 2.6

Levels of salinity recorded in 2010 for the SBOO region during (A) February, (B) May, (C) August, and (D) November. Data are collected over three days during each of these monthly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.

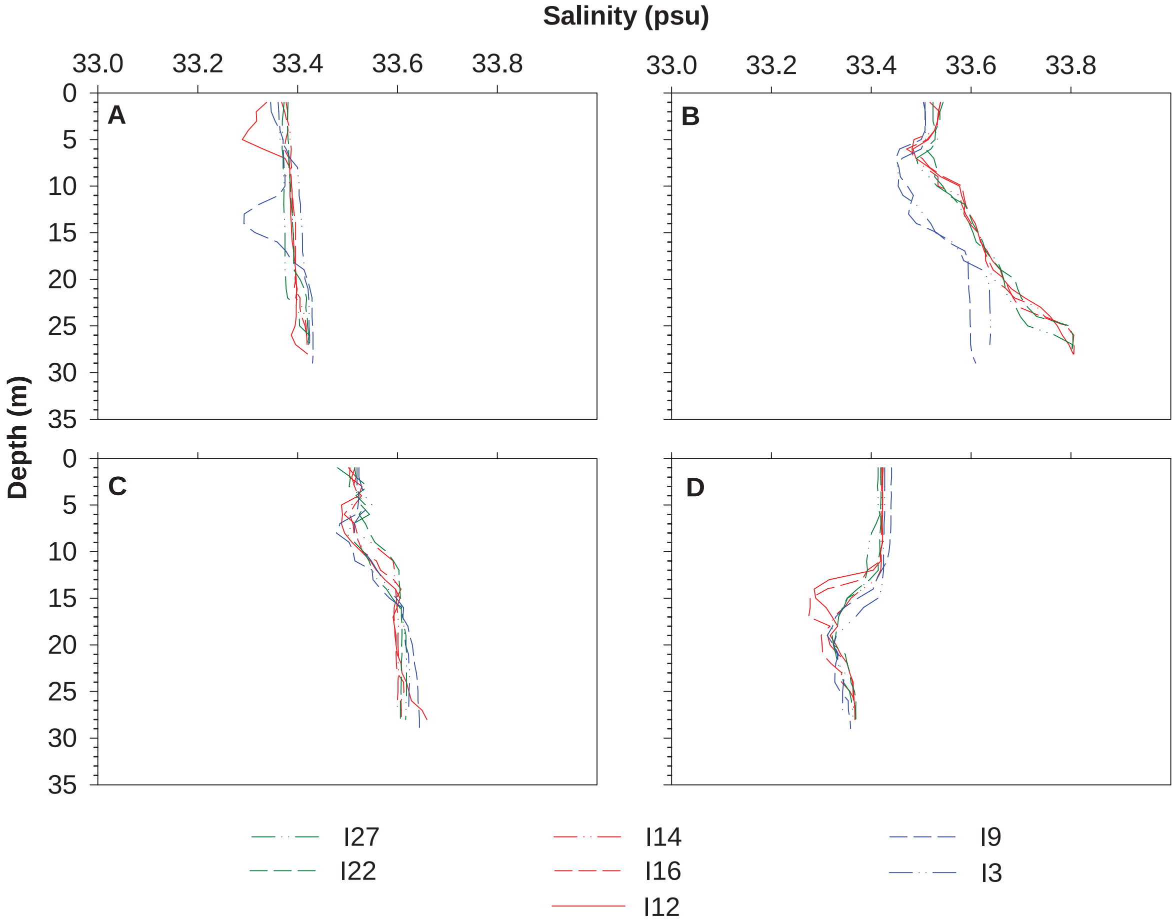


Figure 2.7
Vertical profiles of salinity for SBOO stations during (A) February, (B) May, (C) August, and (D) November 2010.

peaks in chlorophyll concentrations associated with phytoplankton blooms (e.g., Appendices A.5, A.6; see also Svejkovsky 2011). Lower transmissivity along the 9-m depth contour during the winter and fall months may also have been due to wave and storm activity stirring up bottom sediments or particulate-laden runoff. Changes in transmissivity levels relative to wastewater discharge were not discernible during the year.

Chlorophyll a

Mean concentrations of chlorophyll *a* ranged from 0.69 µg/L in bottom waters at the offshore sites during March to 40.63 µg/L at inshore bottom depths in August (Table 2.1). However further analysis clearly showed that the highest chlorophyll values tended to occur at mid- and deeper depths (e.g., Appendix A.6, A.7), reflecting the fact that phytoplankton tend to mass at the bottom of the pycnocline where nutrient levels are greatest. The highest concentrations of chlorophyll for 2010 occurred during May and August across much of the region and corresponded to the coastal upwelling indicated by the low water temperatures, high salinity, and low DO values at bottom depths described above. The relationship between coastal upwelling and subsequent plankton blooms has been well documented by remote sensing imagery over the years (Figure 2.8; Svejkovsky 2011).

Historical Assessment of Oceanographic Conditions

A review of oceanographic data from all stations along the 28-m depth contour sampled between 1995 and 2010 did not reveal any measurable impact that could be attributed to the beginning of wastewater discharge via the SBOO (Figure 2.9). Instead, these data tend to track changes in large

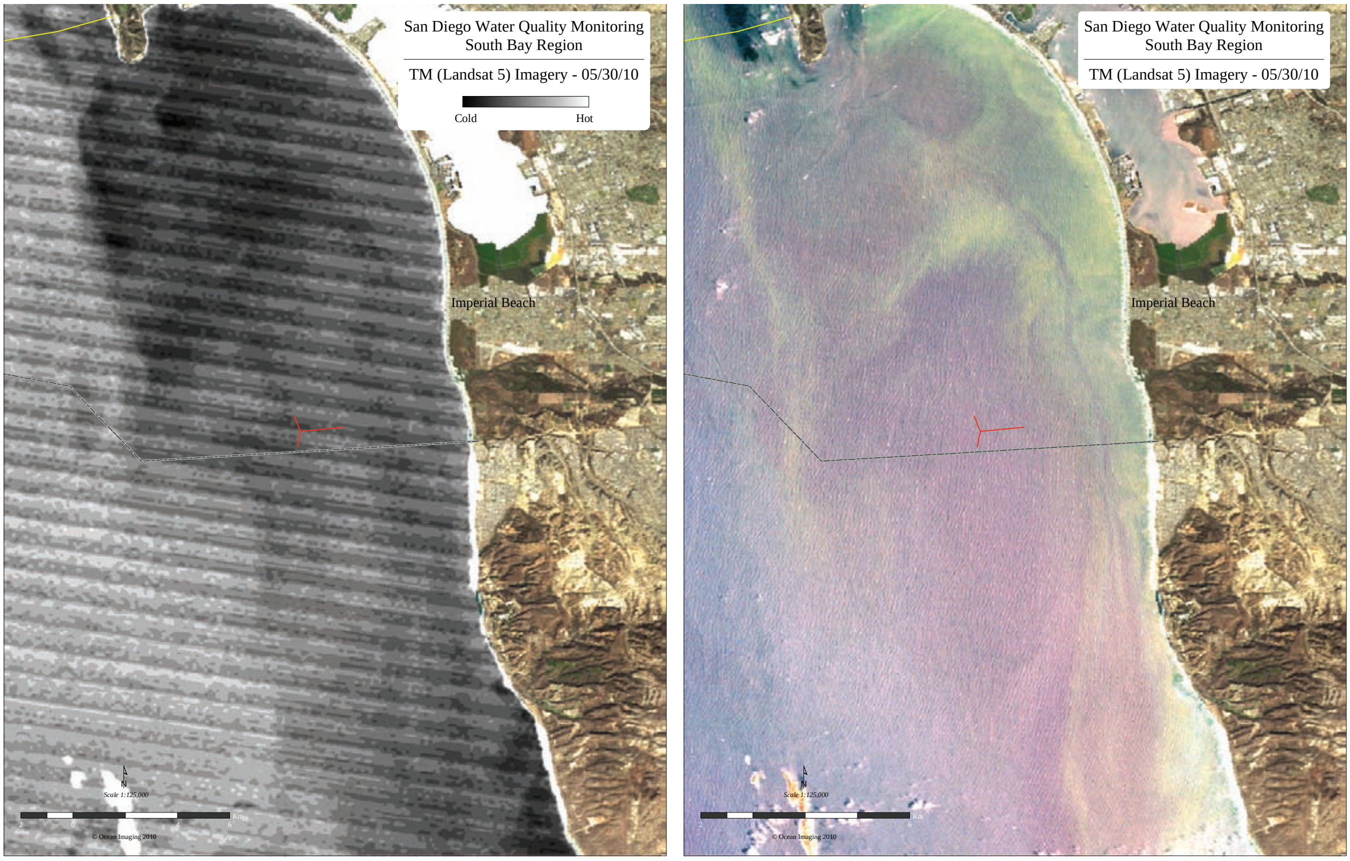


Figure 2.8
Landsat TM5 images of the SBOO and coastal region acquired on May 30, 2010, depicting a coastal upwelling event (left) and a corresponding phytoplankton bloom (right) (from Ocean Imaging 2011).

scale patterns in the California Current System (CCS) observed by CalCOFI (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, NOAA/NWS 2011). For example, six major events have affected the CCS during the last decade: (1) the 1997–1998 El Niño event; (2) a shift to cold ocean conditions between 1999–2002; (3) a subtle but persistent return to warm ocean conditions beginning in October 2002 that lasted through 2006; (4) intrusion of subarctic surface waters resulting in lower than normal salinities during 2002–2004; (5) development of a moderate to strong La Niña event in 2007 that coincided with a cooling of the Pacific Decadal Oscillation (PDO); and (6) development of a second La Niña event starting in May 2010. Temperature and salinity data for the South Bay region are consistent with all but the third of these CCS events; i.e., while the CCS was experiencing a warming trend that lasted through 2006, the SBOO region experienced cooler than normal conditions during 2005 and 2006. The conditions in southern San Diego waters during these two years were more consistent with observations from northern Baja California (Mexico) where water temperatures were well below the decadal mean (Peterson et al. 2006). During 2008 and 2009, temperatures remained cool, but closer to the overall average, whereas 2010 saw the return of cold La Niña conditions.

Water clarity (transmissivity) has generally increased in the South Bay region since 1999, although there have been several intermittent periods when clarity was below normal (Figure 2.9). Transmissivity was much lower than normal during the winter months of several years (e.g., 1998, 2000), likely due to increased suspension of sediments caused by strong storm activity. In addition, below average water clarity events that occur in the spring and early summer months are probably related to plankton blooms such as those observed throughout the region in 2005, 2008,

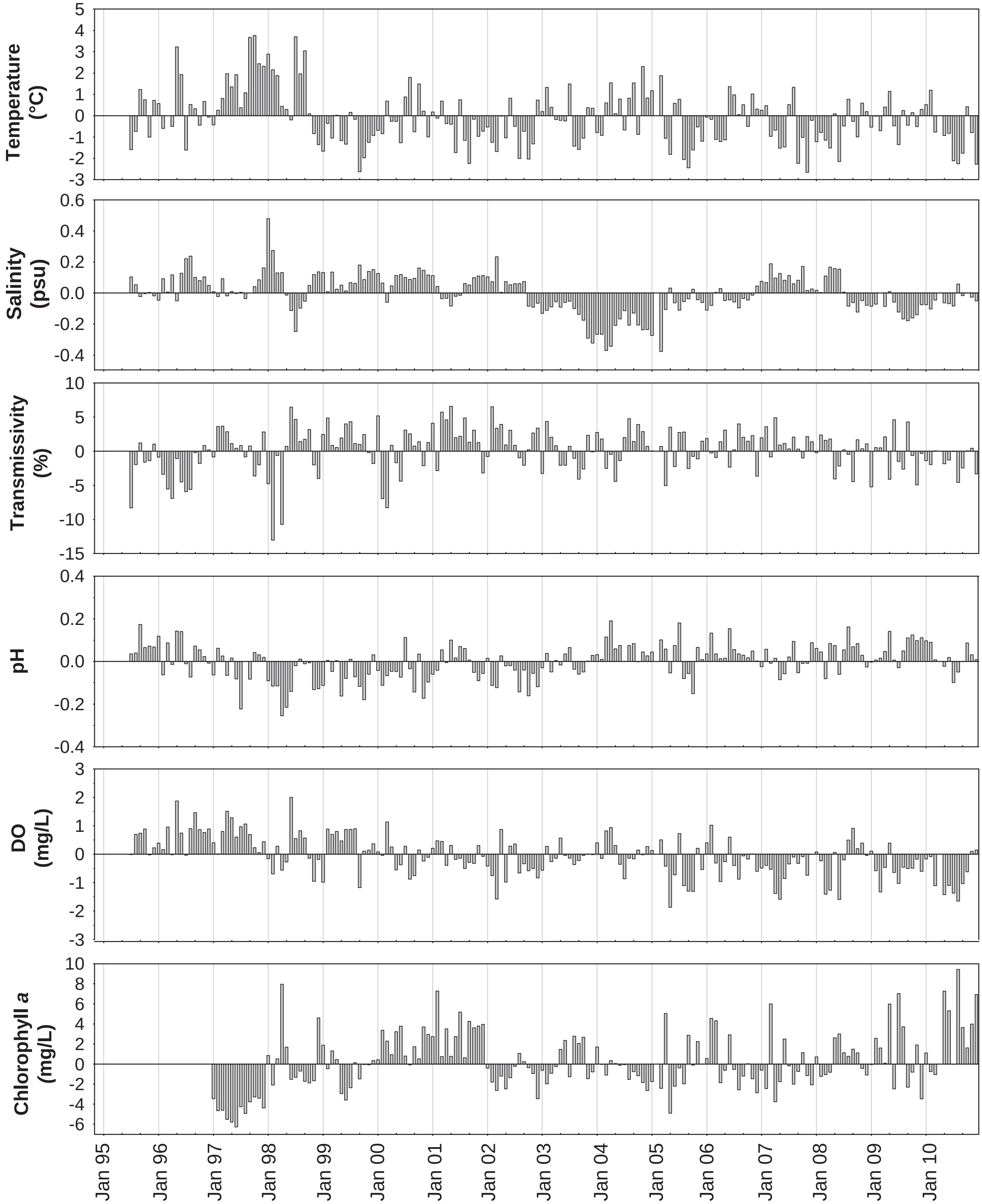


Figure 2.9

Time series of temperature, salinity, transmissivity, pH, dissolved oxygen (DO), and chlorophyll *a* anomalies between 1995 and 2010. Anomalies were calculated by subtracting the monthly means for each year (1995–2010) from the mean of all years combined; data were limited to all stations located along the 28-m depth contour, all depths combined.

2009 and 2010 (see City of San Diego 2006, 2009, 2010 and the discussion in the previous section). In contrast, water clarity during 2006 and 2007 was mostly above the historical average. These latter results are indicative of reduced turbidity due to decreased storm activity and lower rainfall totals of less than 11 inches for these two years.

There were no apparent trends in DO concentrations or pH values related to the SBOO discharge (Figure 2.9). These parameters are complex, dependent on water temperature and depth, and sensitive to physico-chemical and biological processes (Skirrow 1975). Moreover, DO and pH are subject to diurnal and seasonal variations that make temporal changes difficult to evaluate. However, DO values below the historical average appear to be related to low levels of chlorophyll or strong upwelling periods.

Discussion

The South Bay outfall region was characterized by typical seasonal patterns in 2010, which included coastal upwelling and corresponding phytoplankton blooms that were strongest during the spring and summer and occurred across the entire region. Upwelling was indicated by relatively cold, dense, saline waters with low DO levels at mid-depths and below. Plankton blooms were indicated by high chlorophyll concentrations and confirmed by remote sensing observations (i.e., aerial and satellite imagery). Additionally, water column stratification followed typical patterns for the San Diego region, with maximum stratification occurring in late summer and reduced stratification during the winter. Further, oceanographic conditions remained notably consistent with changes in large scale patterns observed by CalCOFI (Peterson et al. 2006, Goericke et al. 2007, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, NOAA/NWS 2011), or they were consistent with data from northern Baja California (Peterson et al. 2006). These observations suggest that other factors such as upwelling of deep offshore waters and large-scale oceanographic events (e.g., El Niño, La Niña) continue to explain most of the temporal and spatial variability observed in oceanographic parameters off southern San Diego.

As expected, satellite and aerial imagery detected the signature of the SBOO wastewater plume in near-surface waters above the discharge site on several occasions between January–March and in December when the water column was less stratified (Svejkovsky 2011). In contrast, the plume appeared to remain deeply submerged between April–November when the thermocline was stronger. Results from bacteriological surveys further support the conclusion that the plume only reached surface or near-surface waters during the winter when the water column was mixed (see Chapter 3). In addition, historical analysis of remote sensing observations made between 2003 and 2009 provides no evidence that the wastewater plume from the SBOO has reached the shoreline (Svejkovsky 2010). These findings were supported in 2010 by the application of IGODS analytical techniques to the oceanographic data collected by the City's ocean monitoring program. For example, while small salinity differences were observed at stations close to the outfall discharge site, it was clear from these analyses that any variations among stations at any particular depth were very slight and highly localized.

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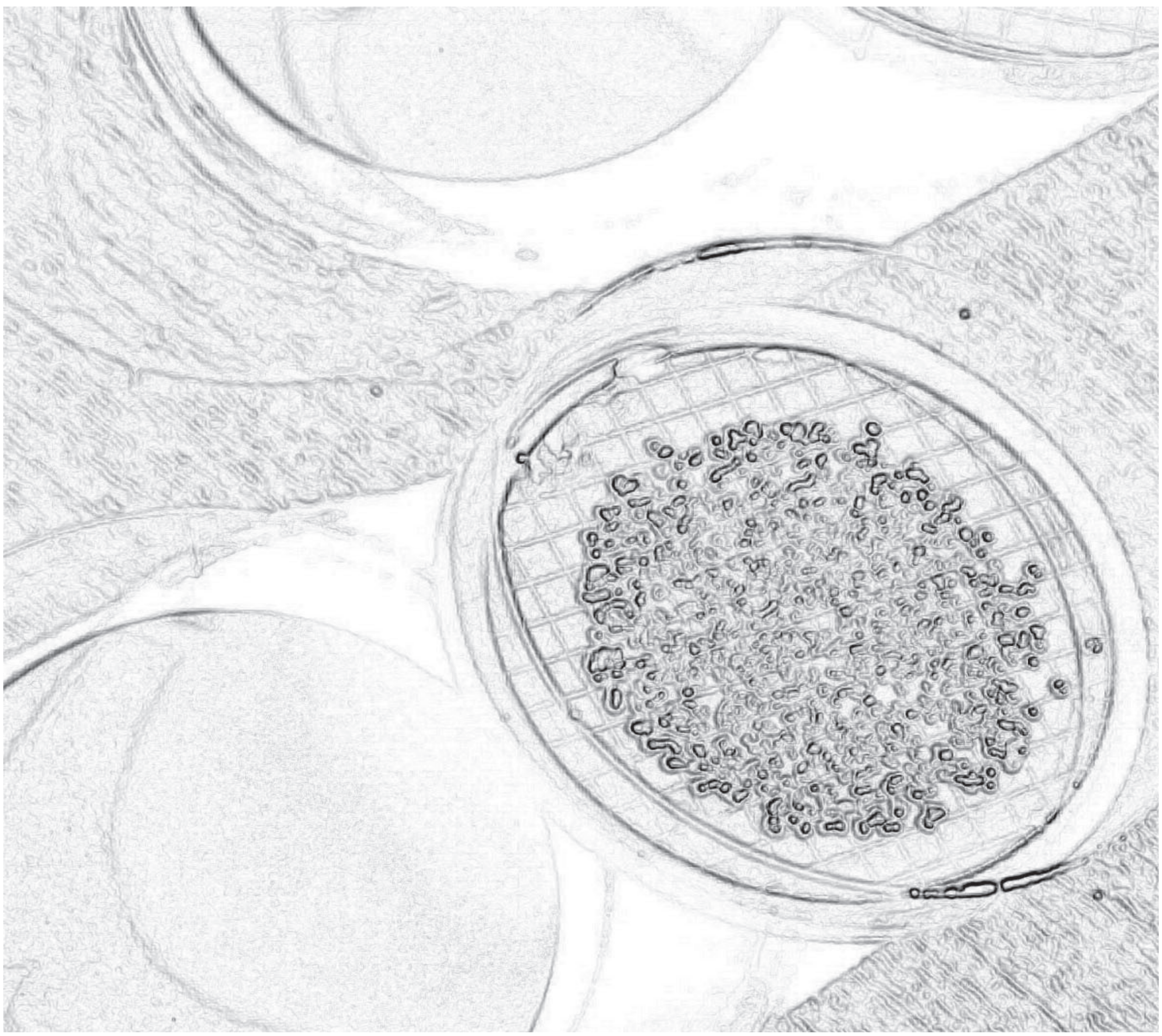
Chapter 3
Water Quality



Chapter 3. Water Quality

INTRODUCTION

Seawater samples are collected and analyzed as part of the South Bay Ocean Outfall (SBOO) monitoring program to characterize water quality conditions in the region and to identify possible impacts of wastewater discharge on the marine environment and along the shoreline. Various water chemistry parameters and densities of fecal indicator bacteria (FIB), including total coliforms, fecal coliforms, and enterococcus, are measured and evaluated along with data on local oceanographic conditions (see Chapter 2) to provide information about the movement and dispersion of wastewater discharged into the Pacific Ocean through the outfall. Evaluation of these data may also help to identify other point or non-point sources of bacterial contamination. In addition, the City's water quality monitoring program is designed to assess compliance with water contact standards as established in the California Ocean Plan (Ocean Plan), which defines bacterial water quality objectives and standards with the intent of protecting the beneficial uses of State ocean waters (SWRCB 2001, 2005).

Because there are multiple natural and anthropogenic sources that can impact water quality, distinguishing a wastewater plume from other sources of bacterial contamination in ocean waters is often challenging. This is especially true in the SBOO region. For example, previous studies in the area have shown that tidal exchange from San Diego Bay, outflows from the Tijuana River in U.S. waters and Los Buenos Creek in northern Baja California, storm water discharges, and runoff from local watersheds have a large impact on nearshore bacteria levels (Noble et al. 2003, Largier et al. 2004, Gersberg et al. 2008, Griffith et al. 2009, Terrill et al. 2009). Likewise, it has been shown that kelp and seagrass beach wracks, storm drains impacted by tidal flushing, and beach sediments can act as reservoirs, cultivating bacteria until high tide returns and/or other disturbances release them into nearshore waters (Gruber et al. 2005, Martin and Gruber 2005). Finally, the presence of birds and their droppings have been related to bacterial exceedances that may impact nearshore water quality (Grant et al. 2001, Griffith et al. 2009).

This chapter presents analyses and interpretations of bacterial densities and water chemistry data collected during 2010 at monitoring sites surrounding the SBOO. The primary goals are to: (1) evaluate overall water quality conditions in the SBOO monitoring region, (2) differentiate among various sources of bacterial contamination into the survey area, including the SBOO wastewater plume, (3) evaluate potential movement and dispersal of wastewater discharged via the SBOO, and (4) assess compliance with water contact standards as defined in the Ocean Plan. In addition, this chapter assesses remote sensing data to provide further insight into the transport potential in coastal waters surrounding the SBOO discharge site.

Materials and Methods

Field Sampling

Seawater samples for bacteriological analyses were collected at a total of 39 shore, kelp bed, or other offshore monitoring sites during 2010 (Figure 3.1). Sampling was performed weekly at 11 shore stations to monitor FIB concentrations in waters adjacent to public beaches. Eight of these stations (S4, S5, S6, S8, S9, S10, S11, S12) are located between the USA/Mexico border and Coronado, southern California and are subject to Ocean Plan water contact standards. The other three shore stations (S0, S2, S3) are located in Mexican waters off northern Baja California and are not subject to Ocean Plan requirements. Three stations located in nearshore waters within the Imperial Beach kelp forest were also monitored weekly to assess water quality conditions and Ocean Plan compliance in areas used for recreational activities such as SCUBA diving, surfing, fishing, and kayaking.

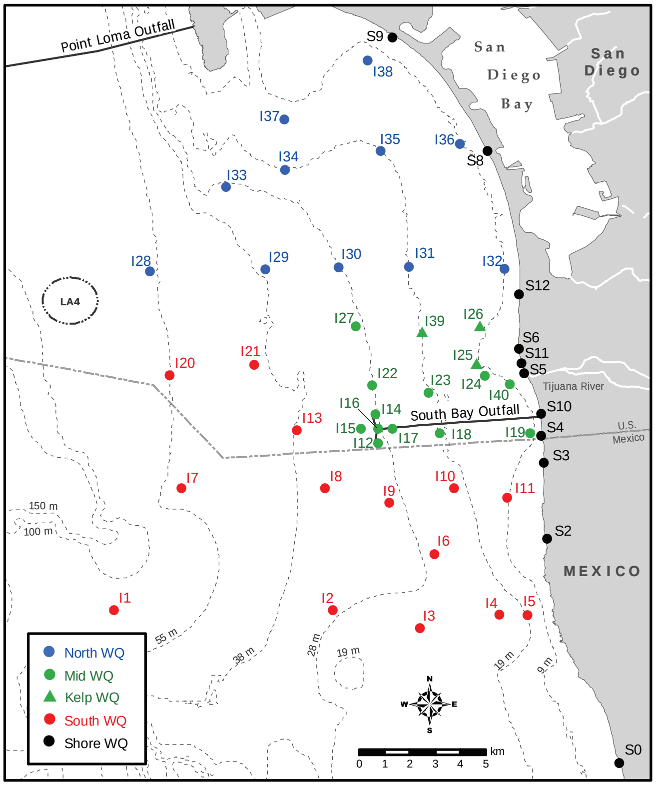


Figure 3.1
Water quality (WQ) monitoring stations for the South Bay Ocean Outfall Monitoring Program.

These include stations I25 and I26 located near the inner edge of the kelp bed along the 9-m depth contour, and station I39 located near the outer edge of the kelp bed along the 18-m depth contour. An additional 25 stations located further offshore in deeper waters were sampled once a month (except April due to a Bight'08 resource exchange) in order to monitor FIB levels and estimate the spatial extent of the wastewater plume. These offshore stations are arranged in a grid surrounding the discharge site distributed along the 9, 19, 28, 38, and 55-m depth contours (Figure 3.1). Sampling of these offshore stations generally occurs over a 3-day period each month (Appendix A.1).

Seawater samples for shore stations were collected from the surf zone in sterile 250-mL bottles. In addition, visual observations of water color, surf height, human or animal activity, and weather conditions were recorded at the time of collection. The samples were then transported on blue ice to the City of San Diego's Marine Microbiology Laboratory (CSDMML) and analyzed to determine FIB concentrations (i.e., total coliform, fecal coliform, and enterococcus bacteria).

Either an array of Van Dorn bottles or a rosette sampler fitted with Niskin bottles was used to collect seawater samples at each of the kelp bed and other offshore stations. Samples were collected at three discrete depths for the above FIBs and total suspended solids (TSS), whereas oil and grease (O&G) samples were only collected from surface waters. Aliquots for each analysis were drawn into appropriate sample containers. All bacterial seawater samples were refrigerated onboard ship and transported to the CSDMML for subsequent processing and analysis. TSS and O&G samples were taken to the City's Wastewater Chemistry Services Laboratory for analysis. Visual observations of weather and sea conditions, and human or animal activity were also recorded at the time of sampling. Monitoring of the SBOO area and neighboring coastline also included aerial and satellite image analysis performed by Ocean Imaging of Solana Beach, California (Svejkovsky 2011).

Laboratory Analyses

All bacterial analyses were performed within 8 hours of sample collection and conformed to standard membrane filtration techniques (APHA 1998). The CSDMML follows guidelines issued by the United States Environmental Protection Agency (USEPA) Water Quality Office, Water Hygiene Division, and the California State Department of Health Services (CDHS) Environmental Laboratory Accreditation Program (ELAP) with respect to sampling and analytical procedures (Bordner et al. 1978, APHA 1998).

Procedures for counting colonies of indicator bacteria, calculation and interpretation of results, data verification and reporting all follow guidelines established by the USEPA (Bordner et al. 1978) and APHA (1998). According to these guidelines, plates with FIB counts above or below the ideal counting range were given greater than (>), less than (<), or estimated (e) qualifiers. However, these qualifiers

Box 3.1

Bacteriological compliance standards for water contact areas, 2001 California Ocean Plan (SWRCB 2001). CFU = colony forming units.

(a) *30-day Total Coliform Standard* — no more than 20% of the samples at a given station in any 30-day period may exceed a concentration of 1000 CFU per 100 mL.

(b) *10,000 Total Coliform Standard* — no single sample, when verified by a repeat sample collected within 48 hrs, may exceed a concentration of 10,000 CFU per 100 mL.

(c) *60-day Fecal Coliform Standard* — no more than 10% of the samples at a given station in any 60-day period may exceed a concentration of 400 CFU per 100 mL.

(d) *30-day Fecal Geometric Mean Standard* — the geometric mean of the fecal coliform concentration at any given station in any 30-day period may not exceed 200 CFU per 100 mL, based on no fewer than five samples.

Bacteriological compliance standards for water contact areas, 2005 California Ocean Plan (SWRCB 2005). CFU = colony forming units.

(a) *30-day Geometric Mean* — The following standards are based on the geometric mean of the five most recent samples from each site:
  1) Total coliform density shall not exceed 1000 CFU/100 mL.
  2) Fecal coliform density shall not exceed 200 CFU/100 mL.
  3) Enterococcus density shall not exceed 35 CFU/100 mL.

(b) *Single Sample Maximum*:
  1) Total coliform density shall not exceed 10,000 CFU/100 mL.
  2) Fecal coliform density shall not exceed 400 CFU/100 mL.
  3) Enterococcus density shall not exceed 104 CFU/100 mL.
  4) Total coliform density shall not exceed 1000 CFU/100 mL when the fecal coliform:total coliform ratio exceeds 0.1.

were dropped and the counts treated as discrete values when calculating means and in determining compliance with Ocean Plan standards.

Quality assurance tests were performed routinely on seawater samples to ensure that sampling variability did not exceed acceptable limits. Duplicate and split bacteriological samples were processed according to method requirements to measure intra-sample and inter-analyst variability, respectively. Results of these procedures were reported in City of San Diego (2011).

Data Treatment

Densities of bacteria were summarized as monthly averages for each shore station and by depth contour for the offshore stations. Total suspended solids (TSS) were also summarized by month for the offshore stations. To assess temporal and spatial trends, bacteriological data were summarized as counts of samples in which FIB concentrations exceeded benchmark levels. For this report, water contact limits defined in the 2005 Ocean Plan for densities of total coliforms, fecal coliforms, and enterococcus in individual samples (i.e., single sample maximums; see Box 3.1 and SWRCB 2005) were used as reference points to distinguish elevated FIB values (i.e., benchmark levels). Concentrations of each FIB are identified by sample in Appendices B.1, B.2, and B.3. In addition, the 2005 Ocean Plan single sample maximum standard that states total coliform densities shall not exceed 1000 CFU/100 mL when the fecal coliform:total coliform (F:T) ratio exceeds 0.1 was considered as the criterion for contaminated waters. This condition is referred to as the fecal:total ratio (FTR) criterion herein. Finally, Pearson's Chi-Square analyses (χ^2)

were conducted to determine if the frequency of samples with elevated FIBs differed between wet versus dry seasons.

Compliance with Ocean Plan water-contact standards was summarized as the number of days that each of the shore stations north of the USA/Mexico border and all of the kelp bed stations exceeded various Ocean Plan standards during each month. Due to regulatory changes that became effective August 1, 2010, bacterial compliance was assessed using the water contact standards specified in the 2001 Ocean Plan (Box 3.1 and SWRCB 2001) between January 1 and July 31, 2010, whereas data collected after August 1, 2010 were assessed using water contact standards specified in the 2005 Ocean Plan (Box 3.1 and SWRCB 2005).

Results

Shore Stations

Concentrations of indicator bacteria generally were higher at the SBOO shore stations in 2010 than in 2009 (City of San Diego 2010), which likely reflects the higher levels of rainfall that occurred during the year (i.e. 16.3 inches in 2010 vs. 5.5 inches in 2009). During 2010, monthly FIB densities averaged from 8 to 16,000 CFU/100 mL for total coliforms, 2 to 10,400 CFU/100 mL for fecal coliforms, and 2 to 7400 CFU/100 mL for enterococcus (Table 3.1). As expected, the highest values for each parameter occurred during the wet season (January–April, October–December). In addition, 85% of the shore station samples with elevated FIBs and 89% of the samples that exceeded the FTR criterion were collected during these months, when rainfall totaled 16.2 inches (vs. 0.08 inches in the dry season; Table 3.2). Further, the proportion of samples that had elevated FIBs during the 2010 wet season was significantly greater than in the dry season [$\chi^2(1, N = 540) = 44.5$, $p < 0.0001$]. This general relationship between rainfall and elevated bacteria levels has been evident over the past several years (Figure 3.2) and these data indicate that there is a 26% greater chance of collecting a sample with elevated FIBs during the wet season [$\chi^2(1, N = 2267) = 137.5$, $p < 0.0001$].

In 2010, samples with elevated FIBs were collected primarily at shore stations close to the mouth of the Tijuana River (i.e., shore stations S4, S5, S10, S11) and further south (i.e., shore stations S0, S2, S3) (Table 3.2, Appendix B.1). High FIB counts at these stations tend to correspond with turbidity plumes from the Tijuana River and Los Buenos Creek (in Mexico), which have been observed repeatedly over the past several years following rain events (City of San Diego 2008–2010). For example, a MODIS satellite image taken February 10, 2010 showed turbidity plumes encompassing several of the shore stations, five of which had elevated total coliform concentrations on the previous day (Figure 3.3). While the image in this figure was not taken on the same day the bacterial samples were collected, the turbidity plume that is evident likely started earlier in the week due to a large storm that began February 5, 2010. Samples from some of these stations (e.g., S0, S2, S5) also had high levels of bacterial contamination during the warmer, dry conditions between May–September (Table 3.2). For example, 12 of the 15 samples with elevated FIB densities that were collected during the dry season occurred at stations S0 and S2, both of which are located south of the international border and bracket Los Buenos Creek. Historically, elevated FIB densities have occurred much more frequently at station S6 and other stations to the south than at stations S8, S9 and S12 located further north (City of San Diego 2007).

Kelp Bed Stations

On average, monthly FIB densities at the SBOO kelp bed stations were lower than those at the shore stations, ranging from 5 to 2208 CFU/100 mL for total coliforms, 2 to 717 CFU/100 mL for fecal coliforms, and 2 to 550 CFU/100 mL for enterococcus (Table 3.3). However, the highest concentrations of these parameters occurred during the wettest months of 2010, similar to the pattern described above for samples collected along the shore. For example, 96% of the kelp bed station

Table 3.1

Summary of rainfall and bacteria levels at SBOO shore stations during 2010. Total coliform, fecal coliform, and enterococcus densities are expressed as mean CFU/100 mL per month and for the entire year. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom; *n* = total number of samples.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Rain (in):		3.38	2.30	0.68	1.78	0.01	0.02	0.02	0.00	0.03	2.18	0.88	5.00
S9	*Total*	106	16	13	11	16	56	65	84	110	910	52	4014
	Fecal	8	7	2	2	2	2	3	11	7	245	3	222
	Entero	39	4	2	2	3	16	4	6	8	317	3	703
S8	*Total*	471	31	21	16	56	16	16	20	20	40	28	4021
	Fecal	26	2	2	2	15	2	2	2	2	4	12	354
	Entero	66	8	4	2	37	3	3	2	13	5	2	506
S12	*Total*	4086	8	20	16	70	48	35	20	25	40	13	4051
	Fecal	208	2	2	7	11	7	5	3	16	19	2	556
	Entero	1602	37	3	2	11	2	6	2	7	28	6	1576
S6	*Total*	4073	1764	7246	4016	20	52	20	16	61	475	52	4050
	Fecal	305	30	186	102	3	2	3	2	3	91	2	758
	Entero	1693	12	15	4	2	3	3	5	2	97	7	2521
S11	*Total*	4195	1195	2721	4085	4020	32	20	16	30	190	21	4156
	Fecal	711	29	33	46	67	2	3	2	5	74	6	3037
	Entero	775	7	6	4	5	2	7	4	4	51	7	3141
S5	*Total*	12,003	13,650	10,816	5160	4020	18	25	20	16	770	1376	4420
	Fecal	4851	6225	2788	3051	1152	2	5	2	2	121	38	3031
	Entero	5802	6011	2460	3024	552	3	4	3	3	32	34	3066
S10	*Total*	8235	12,900	12,400	7556	35	20	25	40	70	86	3408	5347
	Fecal	4204	1603	333	282	2	2	4	3	27	27	330	4001
	Entero	4008	462	702	25	2	2	20	2	17	19	12	1003
S4	*Total*	8004	9310	8320	5081	16	10	35	16	40	111	3428	5341
	Fecal	3551	721	500	112	2	2	5	4	7	25	144	668
	Entero	3802	111	319	8	2	2	4	2	4	12	6	82
S3	*Total*	8013	12,650	16,000	ns	20	44	63	105	213	293	1095	4225
	Fecal	1551	6555	10,400	ns	3	21	10	14	9	66	44	3010
	Entero	1810	5130	7400	ns	2	3	12	10	10	226	87	3021
S2	*Total*	4371	5502	16,000	ns	340	21	437	62	127	1800	740	4410
	Fecal	306	111	470	ns	15	4	86	9	3	35	36	921
	Entero	1758	83	490	ns	8	56	20	4	9	40	8	2138
S0	*Total*	4270	5915	8700	ns	1035	2536	5075	720	697	5420	1915	6625
	Fecal	198	815	235	ns	134	510	355	84	117	475	89	1885
	Entero	1023	1012	360	ns	154	250	314	52	94	324	131	3204
	n	44	44	46	32	44	55	44	55	41	41	52	42
Annual	*Total*	5257	5722	7478	3242	877	259	529	102	128	921	1103	4605
Means	*Fecal*	1447	1463	1359	450	128	51	44	12	18	107	64	1677
	Entero	2034	1170	1069	384	71	31	36	8	15	105	28	1905

ns = not sampled (no samples were collected at stations S0, S2, and S3 from March 16 to April 27 due to travel warnings issued by the U.S. Department of State regarding travel to northern Mexico)

Table 3.2

The number of samples with elevated bacteria densities collected at SBOO shore stations during 2010. Elevated FIB = the total number of samples with elevated FIB densities; contaminated = the total number of samples that meet the FTR criterion indicative of contaminated seawater; Wet = January–April and October–December; Dry = May–September; *n* = total number of samples. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom.

Station		Seasons		
		Wet	Dry	% Wet
S9	Elevated FIB	2	0	100
	Contaminated	1	0	100
S8	Elevated FIB	2	1	67
	Contaminated	0	0	—
S12	Elevated FIB	4	0	100
	Contaminated	1	0	100
S6	Elevated FIB	7	0	100
	Contaminated	2	0	100
S11	Elevated FIB	6	1	86
	Contaminated	2	0	100
S5	Elevated FIB	13	1	93
	Contaminated	11	1	92
S10	Elevated FIB	13	0	100
	Contaminated	5	0	100
S4	Elevated FIB	9	0	100
	Contaminated	4	0	100
S3	Elevated FIB	11	0	100
	Contaminated	7	0	100
S2	Elevated FIB	7	1	88
	Contaminated	1	1	50
S0	Elevated FIB	13	11	54
	Contaminated	5	3	63
	Rain (in)	16.20	0.08	
Total	Elevated FIB	87	15	85
Counts	Contaminated	39	5	89
	n	301	239	56

samples with elevated FIBs and 88% of the samples that met the FTR criterion occurred during the wet season (Table 3.4). Further, the proportion of samples from these stations that had elevated FIBs during the 2010 wet season was also significantly greater than in the dry season [$\chi^2(1, N = 540) = 17.6$, $p < 0.0001$], which is a relationship that has been evident over the past several years (Figure 3.4). Data collected from the kelp stations between 2007 and 2010 indicate that there is 26% greater chance of collecting a sample with elevated FIBs during the wet season [$\chi^2(1, N = 2160) = 68.4$, $p < 0.001$].

High FIB counts in the kelp bed during the rainy season also tended to correspond with turbidity plumes from the Tijuana River and Los Buenos Creek. For example, a MODIS satellite image taken January 24, 2010 showed turbidity plumes encompassing stations I25 and I26, both of which had slightly elevated total coliform concentrations on the following day (Figure 3.5). This turbidity plume likely started earlier in the week due to a large storm that occurred over several days between January 18 and 23, 2010, during which time a total of ~3 inches of rainfall occurred in the SBOO region. In contrast, only one seawater sample collected during the dry season from these stations contained elevated FIB levels (Table 3.4, Appendix B.2). The source of contamination for that sample is unclear.

Total suspended solids (TSS) and oil and grease (O&G) are also measured at the kelp bed stations as potential indicators of wastewater. However, previous analyses have demonstrated that these parameters have limited utility as indicators of the wastefield (City of San Diego 2007). Concentrations of TSS varied considerably during 2010, ranging between 0.2 and 30.9 mg/L per sample (Table 3.5); O&G was not detected in any samples. Of the 39 seawater samples with elevated TSS concentrations ≥8.0 mg/L, none corresponded to samples with elevated FIBs. It is more likely that these high TSS values were due to other sources, such as the re-suspension of bottom sediments when the CTD touched the sea floor, the presence of phytoplankton blooms, or runoff or wave action associated with storm activity that occurred around the time of sampling.

‘Other’ Offshore Stations

Elevated FIB concentrations were rare in samples collected from the 25 non-kelp bed (‘other’) offshore stations during 2010. Only 28 of 825 samples (~3.4%) collected at these sites had elevated FIBs and only 17 (2.1%) met the FTR criterion for contaminated waters (Table 3.4, Appendix B.3). The lack of samples with elevated FIBs reflects the low concentrations of bacteria, which ranged from 2 to 3350 CFU/100 mL for total coliforms, 2 to 946 CFU/100 mL for fecal coliforms, and 2 to 456 CFU/100 mL for enterococcus on average per

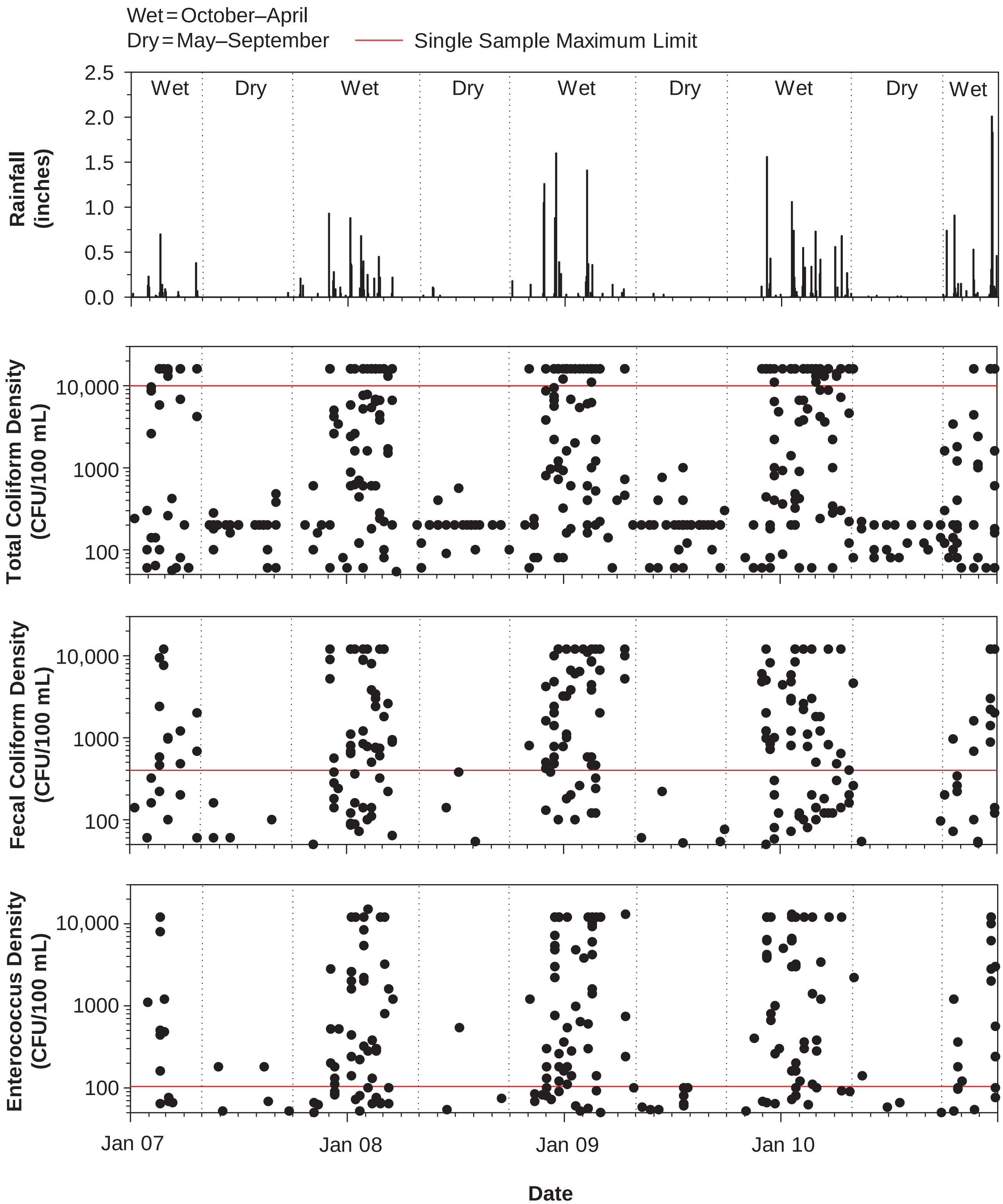


Figure 3.2
Comparison of bacteriological data from SBOO shore stations located north of the USA/Mexico border to rainfall between January 1, 2007 and December 31, 2010. Densities of bacteria have been limited to ≥50 CFU/100 mL for clearer data presentation.

month (Table 3.3). For stations located along the 9 and 19-m depth contours (i.e., I18, I19, I32, I36, I40), 100% of the samples with elevated FIBs were collected during the wet season. As with the shore and kelp stations, remote satellite images demonstrate that contaminants carried by turbidity plumes originating from the Tijuana River and Los Buenos Creek can extend into the offshore sampling region of the SBOO survey area. For example, a MODIS satellite image taken February 24, 2010 showed a turbidity plume associated with increased rainfall moving west and encompassing stations I19 and I40 (Figure 3.6). Samples collected on the previous day at these two stations had elevated total coliform densities, whereas the majority of samples collected farther offshore (i.e., stations I14, I16, I18, I22, I23, I24) had low FIB levels. This turbidity plume likely started earlier in the week due to a large storm that occurred over several days between February 19 and 22, 2010.

During 2010, a total of 14 samples with elevated FIB densities were collected at sites adjacent to the SBOO diffusers (i.e., stations I12 and I16; Table 3.4). Most of these samples were collected from a depth of 18 m or greater, and most also met the FTR criterion for contaminated waters (Appendix B.3). Consequently, it appears likely that these FIB densities were associated with wastewater discharge from the outfall. Further, three samples with elevated FIBs were collected in surface waters during the year. These three samples were collected at stations I12 and I16 in January and February and were likely associated with the surfacing of the wastewater plume in the winter. Aerial imagery results support this conclusion, as they indicated that the wastewater plume reached near-surface waters above the discharge site on several occasions between January and March, and again in December (Figure 2.4; Svejkovsky 2011).

Like the kelp bed stations, TSS and O&G are also measured at the 'other' offshore stations as potential indicators of wastewater. TSS were detected frequently at the offshore stations in 2010 at concentrations that varied considerably between 0.2 and 46.2 mg/L per sample (Table 3.5). In contrast, O&G was detected in only two samples from stations I24 and I36 at concentrations of 1.7 and 1.9 mg/L, respectively. Of the 208 seawater samples with elevated TSS concentrations (≥8.0 mg/L), only 15 corresponded to samples with elevated FIBs, three of which met the FTR criterion for contamination. The remaining elevated TSS values were more likely due to other sources described in the previous section.

California Ocean Plan Compliance

The overall compliance rate for 2010 was about 87%, indicating that compliance with the various Ocean Plan standards (Box 3.1) was relatively high at both shore and kelp stations. During the first half of the year (i.e., January–July), compliance with 2001 Ocean Plan standards along the shore ranged from 31 to 100% for the 30-day total coliform standard, 20 to 100% for the 60-day fecal coliform standard, and 63

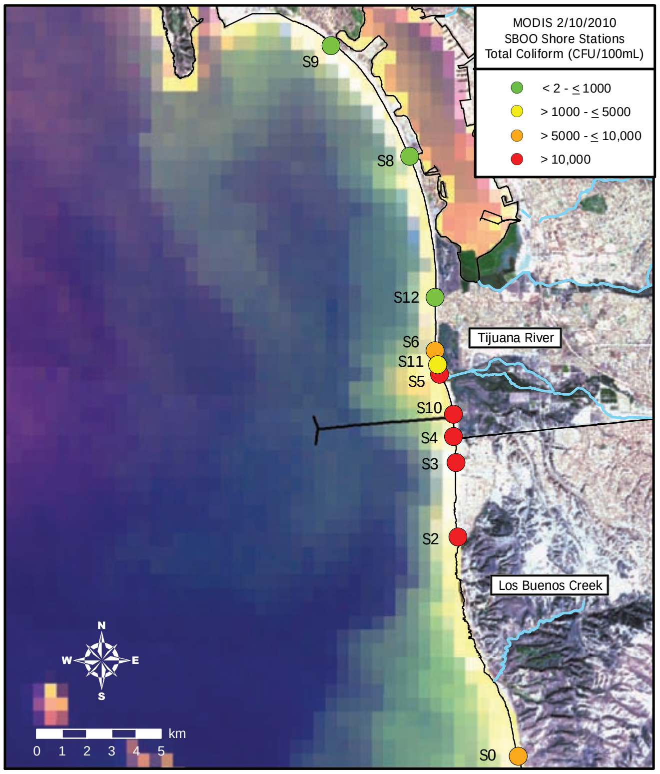


Figure 3.3
MODIS satellite image showing the SBOO monitoring region on February 10, 2010 (Ocean Imaging 2011) combined with total coliform concentrations at shore stations sampled on February 9, 2010. Turbid waters from the Tijuana River and Los Buenos Creek can be seen overlapping southern stations with higher levels of contamination.

Table 3.3

Summary of FIB densities (CFU/100 mL) at SBOO kelp bed and other offshore stations in 2010. Data are expressed as means for all stations along each depth contour by month; n = total number of samples per month.

Assay	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010 SBOO Kelp Bed Stations												
9-m Depth Contour (n = 30)												
Total	713	2208	106	305	20	6	5	7	14	1768	375	164
Fecal	20	66	10	25	2	2	2	2	2	717	34	19
Entero	114	34	13	5	3	2	2	2	2	550	14	107
19-m Depth Contour (n = 15)												
Total	1102	332	52	87	117	6	7	5	19	1102	13	6
Fecal	21	30	7	17	39	2	3	2	2	208	2	2
Entero	60	22	8	4	9	2	2	2	2	25	9	2
2010 SBOO 'Other' Offshore Stations												
9-m Depth Contour (n = 27)												
Total	24	1813	3350	ns	25	27	5	41	20	19	6	7
Fecal	2	45	228	ns	3	2	2	3	3	3	2	2
Entero	2	22	189	ns	2	2	2	2	3	2	2	2
19-m Depth Contour (n = 9)												
Total	29	33	77	ns	8	2	2	3	53	6	467	4
Fecal	2	6	8	ns	2	2	2	2	3	3	58	2
Entero	2	3	5	ns	2	2	2	2	5	2	37	2
28-m Depth Contour (n = 24)												
Total	1416	1717	1401	ns	15	844	1568	66	604	399	1395	19
Fecal	490	114	707	ns	2	500	946	22	239	105	275	2
Entero	335	13	224	ns	2	135	456	6	67	25	7	2
38-m Depth Contour (n = 9)												
Total	84	8	3	ns	2	28	2	10	2	96	2	2
Fecal	4	2	2	ns	2	2	2	2	2	11	2	2
Entero	9	3	2	ns	2	3	2	2	2	4	2	2
55-m Depth Contour (n = 6)												
Total	23	10	2	ns	15	125	2	8	2	3	5	2
Fecal	3	2	2	ns	2	9	2	2	2	2	2	2
Entero	3	3	2	ns	3	6	2	2	2	2	2	2

ns = not sampled (see text)

to 100% for the 30-day fecal geometric mean standard (Appendix B.4). In addition, the shore station samples were out of compliance with the 10,000 total coliform single sample maximum standard 15 times. During the second half of the year (i.e., August–December), compliance with the 2005 Ocean Plan standards at shore stations ranged from 95 to 100% for the 30-day total coliform geometric mean standard and from 88 to 99% for the enterococcus geometric mean standard; shore stations were 100% compliant with the fecal coliform geometric mean standard (Appendix B.5). In addition, the single sample maximum (SSM) standard for total coliforms was exceeded 20 times, while the SSM for fecal coliforms was exceeded 21 times, the SSM for enterococcus was exceeded 32 times, and the SSM based on the fecal:total coliform ratio was exceeded 18 times. Differences in compliance rates during the year generally reflected trends in elevated bacterial levels, with compliance being the lowest between the months of January–March and in December when rainfall was greatest.

Compliance rates for samples collected at the three kelp bed stations tended to be higher than at the

Table 3.4

The number of samples with elevated bacteria densities collected at SBOO kelp bed and other offshore stations during 2010. Elevated FIB = the total number of samples with elevated FIB densities; contaminated = the total number of samples that meet the FTR criterion indicative of contaminated seawater; Wet = January–April and October–December; Dry = May–September; Rain data are from Lindbergh Field, San Diego, CA. Offshore stations not listed had no samples with elevated FIB concentrations in 2010.

Station		Wet	Dry	% Wet
2010 SBOO Kelp Bed Stations				
Total No. of Samples		315	225	
Elevated FIBs		27	1	96
Contaminated		7	1	88
9-m Depth Contour				
I25	Elevated FIB	10	0	100
	Contaminated	2	0	100
I26	Elevated FIB	11	0	100
	Contaminated	3	0	100
19-m Depth Contour				
I39	Elevated FIB	6	0	100
	Contaminated	2	0	100
2010 SBOO 'Other' Offshore Stations				
Total No. of Samples		198	375	
Elevated FIBs		20	8	71
Contaminated		10	7	59
9-m Depth Contour				
I19	Elevated FIB	3	0	100
	Contaminated	0	0	—
I36	Elevated FIB	1	0	100
	Contaminated	0	0	—
I32	Elevated FIB	3	0	100
	Contaminated	1	0	100
I40	Elevated FIB	1	0	100
	Contaminated	0	0	—
19-m Depth Contour				
I18	Elevated FIB	1	0	100
	Contaminated	1	0	100
28-m Depth Contour				
I9	Elevated FIB	1	1	50
	Contaminated	1	1	50
I12	Elevated FIB	5	2	71
	Contaminated	2	2	50
I16	Elevated FIB	5	2	71
	Contaminated	5	2	71
I30	Elevated FIB	0	3	0
	Contaminated	0	2	0

shore stations, which reflects the lower levels of FIBs found in these samples. Compliance during the first half of 2010 with the 2001 Ocean Plan Standards at these sites ranged at from 75 to 99% for the 30-day total coliform standard and they were never out of compliance with the 60-day fecal coliform standard, the 30-day fecal geometric mean standard, or the 10,000 total coliform single sample maximum standard. As compared with the 2005 Ocean Plan Standards during the second half of the year, compliance with the 30-day enterococcus geometric mean standard ranged from 88 to 100%, whereas compliance with the 30-day total and 30-day fecal coliform geometric mean standards was 100%. The SSM standards were exceeded between 3 and 13 times at kelp stations.

Discussion

Overall water quality conditions in the SBOO monitoring region were good during 2010, as indicated by relatively high overall compliance (87%) with accepted water-contact bacterial standards. In addition, there was no evidence during the year that wastewater discharged to the ocean via the SBOO reached the shoreline or nearshore recreational waters. Although elevated FIBs were detected along the shore, and occasionally at the kelp bed or other nearshore stations, these results likely do not indicate shoreward transport of the SBOO wastewater plume, a conclusion consistently supported by the lack of shoreward movement of the plume evident in remote sensing images collected over several years (Svejkovsky 2010). Instead, analysis of FIB distributions and the results of satellite imagery data indicate that other sources such as outflows from the Tijuana River and Los Buenos Creek are more likely to have impacted water quality along the shore and in nearshore recreational waters in the South Bay outfall region. For example, the shore stations located near the Tijuana River and Los Buenos Creek have historically had higher numbers of contaminated samples than stations located farther to the north (City of San Diego 2007–2010). Further, long-term analyses of various water quality parameters have demonstrated that the general relationship between

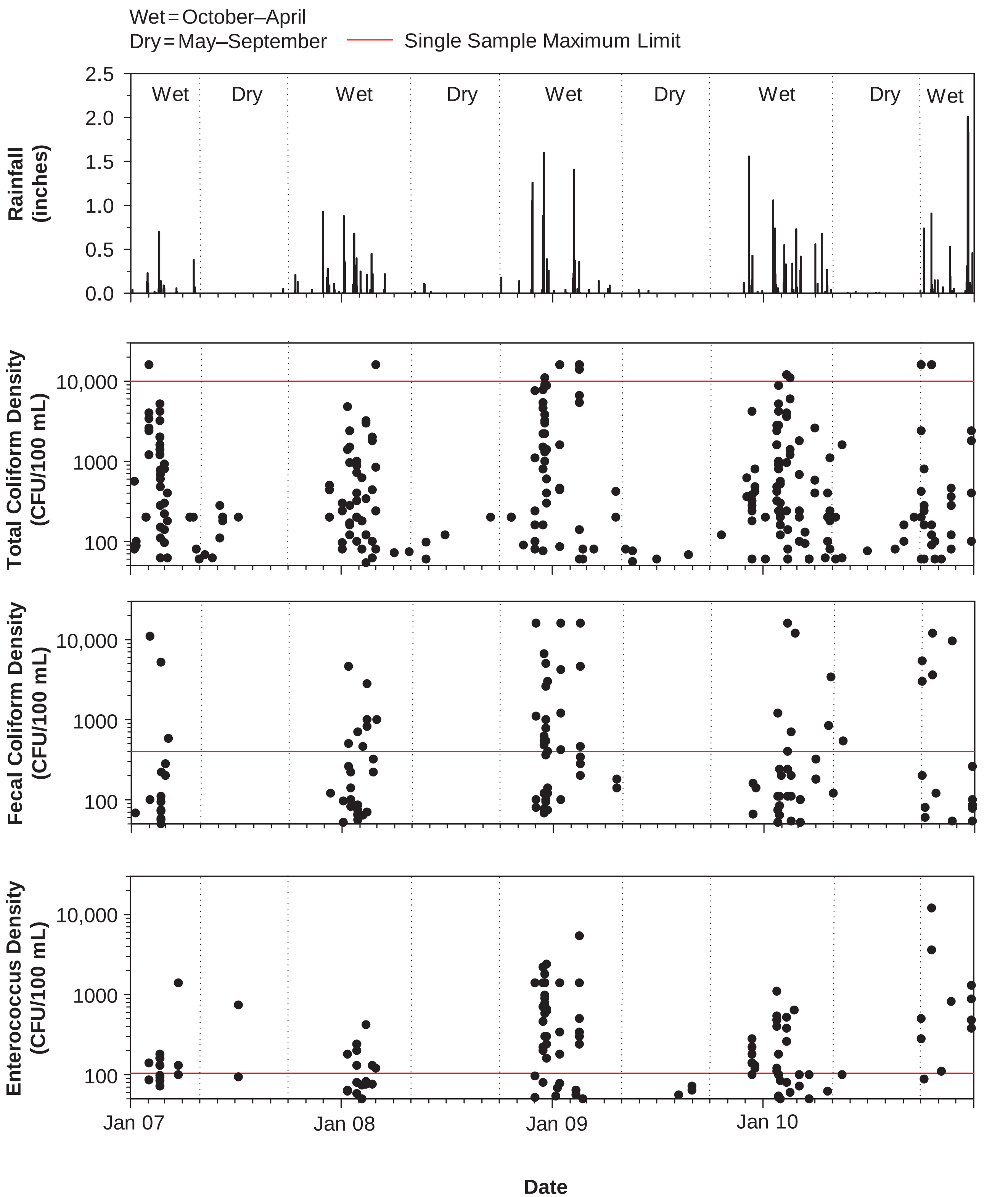


Figure 3.4
Comparison of bacteriological data from SBOO kelp stations to rainfall between January 1, 2007 and December 31, 2010. Densities of bacteria have been limited to ≥50 CFU/100 mL for clearer data presentation.

Table 3.5

Summary of total suspended solid (TSS) concentrations in samples collected from the SBOO kelp bed and other offshore stations in 2010. Data include the number of detected values (*n*), as well as minimum, maximum, and mean detected concentrations for each month. The method detection limit = 1.6 mg/L for TSS.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010 SBOO Kelp Bed Stations (*n* = 9)												
Min	5.18	5.38	2.51	ns	2.71	3.85	5.16	3.13	0.20	2.42	3.43	6.07
Max	8.32	30.90	10.70	ns	15.60	10.10	10.40	12.30	19.60	6.76	8.37	15.70
Mean	6.94	14.17	7.44	ns	7.15	6.99	7.37	6.28	9.60	4.80	5.45	11.03
2010 SBOO 'Other' Offshore Stations (*n* = 75)												
Min	3.55	3.44	0.20	ns	1.89	1.90	2.30	1.74	1.99	1.77	1.78	0.20
Max	14.60	46.20	23.90	ns	18.70	22.80	24.90	12.60	19.10	17.10	13.70	18.50
Mean	6.82	9.57	7.14	ns	7.19	5.80	5.46	5.67	6.66	5.74	5.67	6.24

ns = not sampled (see text)

rainfall and elevated FIB levels has remained consistent since ocean monitoring began in 1995, including the period prior to wastewater discharge (City of San Diego 2000). It is well established that contaminated waters originating from the Tijuana River and Los Buenos Creek are likely sources of bacteria during periods of increased flows in the SBOO region (e.g., during storms or extreme tidal exchanges) (Noble et al. 2003, Largier et al. 2004, Gersberg et al. 2008, Terrill et al. 2009). Such

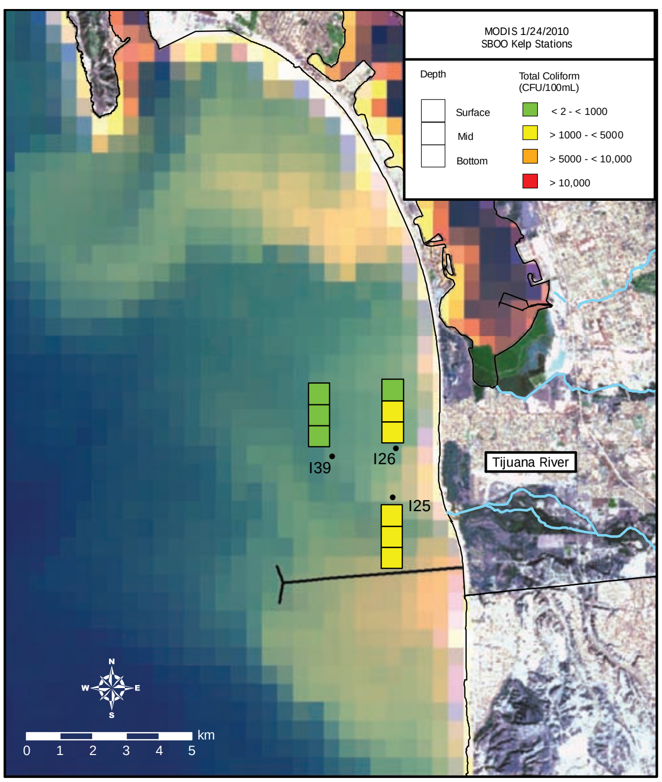


Figure 3.5

MODIS satellite image showing the SBOO monitoring region on January 24, 2010 (Ocean Imaging 2011) combined with total coliform concentrations at kelp stations sampled on January 25, 2010. Turbid waters from the Tijuana River can be seen overlapping the kelp bed stations.

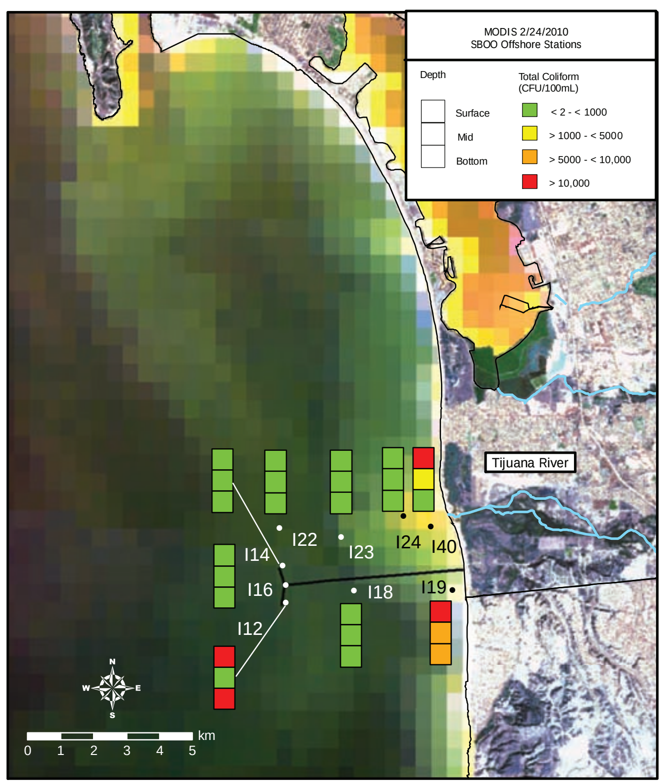


Figure 3.6

MODIS satellite image showing the SBOO monitoring region on February 24, 2010 (Ocean Imaging 2011) combined with total coliform concentrations at offshore stations sampled on February 23, 2010. Turbid waters from the Tijuana River can be seen overlapping stations where contamination was high nearshore.

contaminants may originate from various sources, including sod farms, surface runoff not captured by the canyon collection system, the Tijuana estuary (e.g., decaying plant material), and partially treated effluent from the San Antonio de los Buenos Wastewater Treatment Plant (SABWTP).

During 2010, the majority of elevated FIB densities not associated with rainfall events occurred at shore stations south of the border near known sources of contamination (e.g., the SABWTP) or at a few offshore sites located within 1000 m of the SBOO diffusers at a depth of 18 m or greater. Only three samples with elevated FIBs were collected at the surface near the SBOO during the year, although remote sensing observations did detect the signature of the wastewater plume in near-surface waters over the discharge site on several occasions during the winter. The low incidence of contaminated waters during winter at the surface and at depth may be due to chlorination of IWTP effluent, which typically occurs between November and April each year. The lack of elevated bacteria levels in surface waters during the summer is expected, as those are the months when the water column is well stratified and the wastefield remains trapped beneath the thermocline.

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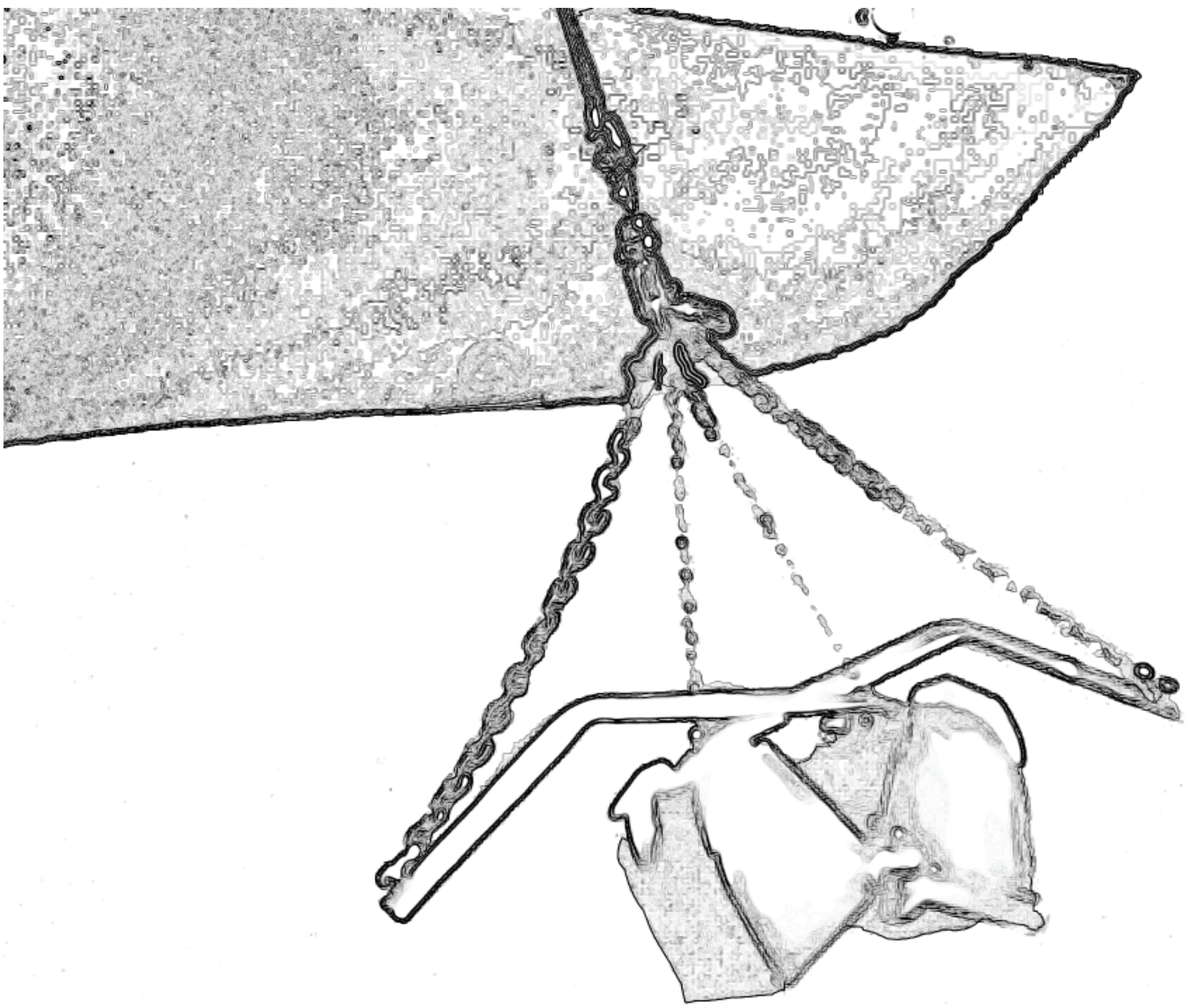
Chapter 4
Sediment Conditions



Chapter 4. Sediment Conditions

INTRODUCTION

Ocean sediment samples are collected and analyzed as part of the South Bay Ocean Outfall (SBOO) monitoring program to characterize the general sediment quality in the region and to assess the potential impacts of wastewater discharge to the marine benthos. Analysis of parameters such as sediment particle size, sorting coefficients, and the relative percentages of coarse (e.g., gravel and sand) and fine (e.g., silt and clay) fractions provide useful information about current velocity, wave action, and overall habitat stability. Additionally, particle size composition can often be used to explain concentrations of chemical constituents within sediments since levels of organic compounds and trace metals generally rise with increasing amounts of fine particles (Emery 1960, Eganhouse and Venkatesan 1993). Finally, physical and chemical sediment characteristics are monitored because they define the primary microhabitats for benthic invertebrates that live within or on the seafloor, and subsequently influence the distribution and presence of various species. For example, differences in sediment composition and associated levels of organic loading affect the burrowing, tube building, and feeding abilities of infaunal invertebrates, thus affecting benthic community structure (Gray 1981, Snelgrove and Butman 1994). Also, many demersal fish species are associated with specific sediment types that reflect the habitats of their preferred invertebrate prey (Cross and Allen 1993). Overall, understanding the differences in sediment conditions and quality over time and space is crucial to assessing coincident changes in benthic invertebrate and demersal fish populations (see Chapters 5 and 6, respectively).

Both natural and anthropogenic factors affect the composition, distribution, and stability of seafloor sediments on the continental shelf. Natural factors that affect sediment conditions include geologic history, strength and direction of bottom currents, exposure to wave action, seafloor topography, inputs associated with outflows from rivers and bays, beach erosion, runoff from other terrestrial sources, bioturbation by fish and benthic invertebrates, and decomposition of calcareous organisms (Emery 1960). These processes affect the size and distribution of sediment types, and also sediment chemical composition. For example, erosion from coastal cliffs and shores, and flushing of terrestrial sediment and debris from bays, rivers, and streams augment the overall organic content and grain size of coastal sediments. These inputs can also contribute to the deposition and accumulation of trace metals or other contaminants to the sea floor. Primary productivity by marine phytoplankton and decomposition of marine and terrestrial organisms are also major sources of organic loading to coastal shelf sediments (Mann 1982, Parsons et al. 1990).

Municipal wastewater outfalls are one of many anthropogenic factors that can directly influence the composition and distribution of sediments through the discharge of treated effluent and the subsequent deposition of a wide variety of organic and inorganic compounds. Some of the most commonly detected contaminants discharged via ocean outfalls are trace metals, pesticides, and various organic compounds such as organic carbon, nitrogen, and sulfides (Anderson et al. 1993). In particular, organic enrichment by wastewater outfalls is of concern because it may impair habitat quality for benthic marine organisms and thus disrupt ecological processes. For example, sulfides, which are the byproducts of the anaerobic breakdown of organic matter, can be toxic to some benthic species if the sediments become excessively enriched (Gray 1981). Additionally, nitrogen enrichment can lead to sudden phytoplankton blooms in coastal waters, resulting in further organic loading (see above). Other contaminants originating from anthropogenic sources, such as trace metals and pesticides, may become incorporated into the tissues of organisms living near or within these marine sediments, and accumulate within the food web (see Chapter 7). Lastly, the physical presence of a large outfall pipe

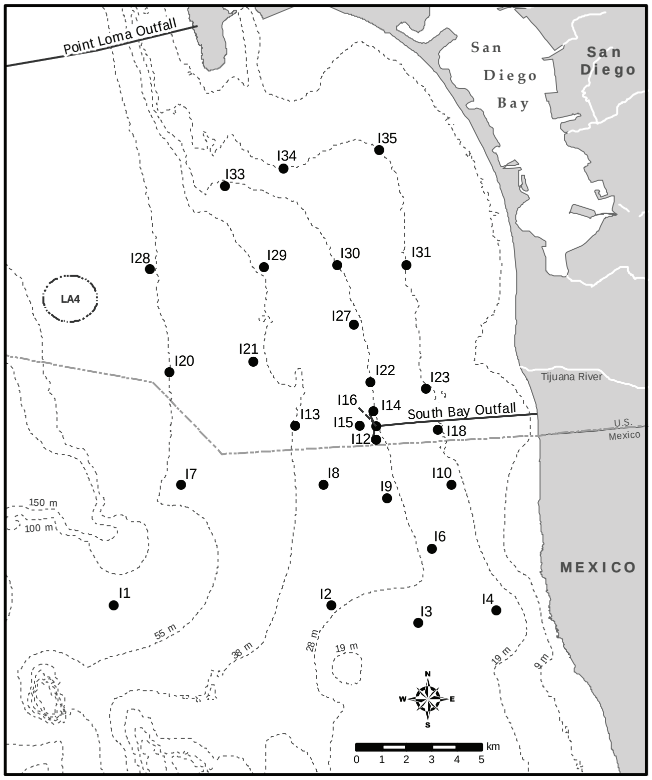


Figure 4.1
Benthic station locations sampled for the South Bay Ocean Outfall Monitoring Program.

and associated ballast materials (e.g., rock, sand) may alter the hydrodynamic regime in surrounding areas, thus affecting sediment movement and transport, and the resident biological communities.

This chapter presents analyses and interpretations of sediment particle size and chemistry data collected during 2010 at monitoring sites surrounding the SBOO. The primary goals of this chapter are to: (1) characterize the spatial and temporal variability of sediment parameters in order to assess possible effects of wastewater discharge on benthic habitats, (2) determine the presence or absence of sediment or contaminant deposition near the discharge site, and (3) evaluate overall sediment quality in the region.

Materials and Methods

Field Sampling

Sediment samples were collected at 27 benthic stations in the SBOO region during January and July 2010 (Figure 4.1). These stations range in depth from 18 to 60 m and are distributed along or adjacent to four main depth contours. The four stations considered to represent "nearfield" conditions herein (i.e., I12, I14, I15, I16) are located within 1000 m of the outfall wye. Each sediment sample was collected from one side of a chain-rigged double Van Veen grab with a 0.1-m^2 surface area; the other grab sample from the cast was used for macrofaunal community analysis (see Chapter 5) and visual observations of sediment composition. Sub-samples for various analyses were taken from the top 2 cm of the sediment surface and handled according to standard guidelines available in USEPA (1987).

Laboratory Analyses

All sediment chemistry and particle size analyses were performed at the City of San Diego's Wastewater Chemistry Services Laboratory. Particle size analysis was performed using either a Horiba LA-920 laser scattering particle analyzer or a set of six nested sieves. The Horiba analyzer measures particles ranging in size from 0.00049 mm to 2.0 mm (i.e., 11 to -1 phi). Coarser sediments from these samples were removed prior to laser analysis by screening the samples through a 2.0 mm mesh sieve. These data were later combined with the Horiba results to obtain a complete distribution of particle sizes totaling 100%. When a sample contained substantial amounts of coarse materials (e.g., coarse sand, gravel, shell hash) that would damage the Horiba analyzer and/or where the general distribution of sediment sizes would be poorly represented by laser analysis, a set of six nested sieves was instead used to separate the grain size fractions. The mesh sizes of the sieves are 2.0 mm, 1.0 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.063 mm, and separate a seventh fraction of all particles finer than 0.063 mm. In 2010, 51 samples were processed by laser analysis and 3 samples (I28 in January and July, and I23 in July) were processed by sieve analysis. Results from the sieve analysis and output from the Horiba were categorized into phi sizes based on the Wentworth scale (Appendix C.1). These phi sizes were then used in the calculation of various particle size parameters, which were determined using a normal probability scale (see

Folk 1980). Summaries of particle size parameters included overall mean particle size (mm), phi size (mean, standard deviation, skewness, kurtosis), and the proportion of coarse, sand, silt, and clay. Additionally, the proportion of fine particles (percent fines) was calculated as the sum of all silt and clay fractions for each sample.

Each sediment sample was chemically analyzed to determine concentrations of total organic carbon (TOC), total nitrogen (TN), total sulfides, trace metals, chlorinated pesticides (e.g., DDT), polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs) on a dry weight basis (see Appendix C.2). TOC, and TN were measured as percent weight (% wt) of the sediment sample; sulfides and metals were measured in units of mg/kg and are expressed in this report as parts per million (ppm); pesticides and PCBs were measured in units of ng/kg and are expressed as parts per trillion (ppt); PAHs were measured in units of µg/kg and are expressed as parts per billion (ppb). Reported values were generally limited to values above the method detection limit (MDL) for each parameter. However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry. A more detailed description of the analytical protocols is provided by the Wastewater Chemical Services Laboratory (City of San Diego 2011).

Data Analyses

Data summaries for the various sediment parameters measured during 2010 included detection rates, annual means of detected values for all stations combined (areal mean), and minimum, median, and maximum values during the year. Total chlordane, total DDT (tDDT), total PCB (tPCB), and total PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values (see Appendix C.3 for individual constituent values). Statistical analyses included Spearman rank correlation of percent fines with each chemical parameter. This non-parametric analysis accommodates non-detects (i.e., analyte concentrations measured below the MDL) without the use of value substitutions (Helsel 2005). However, depending on the data distribution, the instability in ranked-based analyses may intensify with increased censoring (Conover 1980). Therefore, a criterion of $<50\%$ non-detects was used to screen eligible constituents for this analysis. In addition, only parameters analyzed with a single MDL throughout the entire year were considered for correlation analysis (Helsel 2005). Correlation results were confirmed visually by graphical analyses.

Data from the 2010 surveys were compared to the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines of Long et al. (1995) when available to assess contamination levels. The National Status and Trends Program of the National Oceanic and Atmospheric Administration (NOAA) originally established the ERLs and ERMs to provide a means for interpreting environmental monitoring data. The ERLs represent chemical concentrations below which adverse biological effects are rarely observed. Values above the ERL but below the ERM represent values at which effects occasionally occur. Concentrations above the ERM indicate likely biological effects, although these are not always validated by toxicity testing (Schiff and Gossett 1998). Contamination levels were further evaluated by comparing results for the current year with historical data, including comparisons between the maximum values for 2010 to those from the pre-discharge period (i.e., 1995–1998).

Results

Particle Size Distribution

Ocean sediments were diverse at the benthic stations sampled around the SBOO in 2010. Sands composed the largest fraction at all stations, ranging from 65.2% to 98.7% of each sample, whereas fines (silt and clay) ranged from 0% to 31.5% (Table 4.1). Overall, there were no spatial patterns in particle size composition relative to the SBOO discharge site during the year

Table 4.1

Summary of particle size and sediment chemistry parameters at SBOO benthic stations during 2010. Data include the detection rate (DR), areal mean of detected values, and minimum, median, and maximum values for the entire survey area. The maximum value from the pre-discharge period (i.e., 1995–1998) is also presented. ERL = Effects Range Low threshold; ERM = Effects Range Median threshold; SD = standard deviation.

	2010 Summary*					Pre-discharge		
Parameter	**DR (%)**	**Areal Mean**	**Min**	**Median**	**Max**	**Max**	**ERL**	**ERM**
Particle Size								
Mean *(mm)*	**	0.269	0.080	0.143	0.660	0.758	na	na
Mean *(phi)*	**	2.27	0.60	2.81	3.65	4.20	na	na
SD *(phi)*	**	0.87	0.48	0.80	1.68	2.50	na	na
Coarse *(%)*	**	3.9	0.0	0.0	16.5	52.5	na	na
Sand *(%)*	**	87.2	65.2	89.3	98.7	100.0	na	na
Fines *(%)*	**	8.9	0.0	8.1	31.5	47.2	na	na
Organic Indicators								
Sulfides *(ppm)*	89	1.21	nd	0.81	4.72	222.00	na	na
TN *(% weight)*	98	0.019	nd	0.016	0.044	0.077	na	na
TOC *(% weight)*	98	0.140	nd	0.109	0.769	0.638	na	na
Trace Metals (ppm)								
Aluminum	100	3818	677	3265	9700	15,800	na	na
Antimony	24	0.53	nd	nd	1.18	5.60	na	na
Arsenic	98	2.16	nd	1.55	7.64	10.90	8.2	70
Barium	100	19.76	1.92	20.80	46.70	54.30	na	na
Beryllium	7	0.05	nd	nd	0.10	2.14	na	na
Cadmium	33	0.11	nd	nd	0.43	0.41	1.2	9.6
Chromium	100	9.1	3.5	9.5	16.9	33.8	81	370
Copper	91	3.78	nd	3.36	9.06	11.10	34	270
Iron	100	5393	1070	5465	11,700	17,100	na	na
Lead	100	2.29	1.01	1.83	5.22	6.80	46.7	218
Manganese	100	42.0	5.8	39.5	95.2	162.0	na	na
Mercury	41	0.008	nd	nd	0.021	0.078	0.15	0.71
Nickel	100	2.46	0.63	2.11	8.19	13.60	20.9	51.6
Selenium	0	—	nd	nd	nd	0.620	na	na
Silver	4	0.22	nd	nd	0.29	nd	1	3.7
Thallium	2	0.8	nd	nd	0.8	17.0	na	na
Tin	65	0.5	nd	0.4	1.2	nd	na	na
Zinc	100	11.7	2.2	10.0	31.9	46.9	150	410
Pesticides (ppt)								
Total DDT	26	319	nd	nd	1100	23,380	1580	46,100
HCB	20	100	nd	nd	220	nd	na	na
Total PCB (ppt)	4	182	nd	nd	290	na	na	na
Total PAH (ppb)	0	—	nd	nd	nd	636.5	4022	44,792

na = not available; nd = not detected

* Minimum, median, and maximum values were calculated based on all samples (*n* = 54), whereas means were calculated on detected values only (*n* ≤ 54).

** Particle size parameters calculated for all samples.

(Figure 4.2). Sediments collected from the nearfield stations were similar to those from the surrounding area in that they contained low levels of fine material (i.e., ≤15.4% fines; Appendix C.4). Likewise, there has been no evidence of increased fine particles near the outfall (or in the region) since the onset of

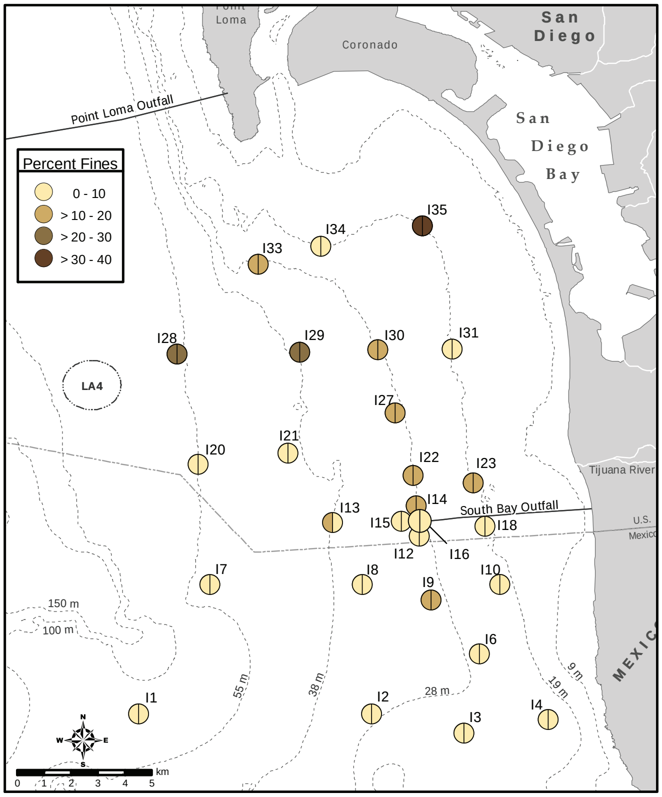


Figure 4.2

Distribution of fine sediments (percent fines) at SBOO benthic stations sampled during 2010. Split circles show results of January (left) and July (right) surveys.

wastewater discharge in 1999 (Figure 4.3). Instead, the highest percent fines tend to occur at stations I28, I29 and I35, located to the north in the survey region (Figure 4.2) (City of San Diego 2008–2010).

The diversity of sediments in the SBOO region reflects not just the variability in the amount of fine material present, but also the types of coarser materials. While most SBOO samples had similarly shaped unimodal particle size distributions, the single modal peak for these samples ranged from phi 1 to 4, thus indicating a wide range in the type of sands present (i.e., coarse to very fine; Appendix C.5). Visual observations confirm that there was substantial variability in the types of sands and coarse sediments making up the samples, including red relict sands, coarse black sands, gravel, and shell hash (Appendix C.4). The only deviation from the pattern described above occurred at station I28; sediments at this station appeared bimodal, with peaks around phi 1–2 (coarse and medium sand) and 4–5 (very fine sand and coarse silt).

Temporal differences in particle size distribution between the winter and summer surveys were minimal. For example, intra-station particle size composition differed by less than 10% at most sites between the January and July surveys (Appendix C.4). Only stations I3 and I13 displayed higher between-survey differences in the percent contribution of each size fraction. For example, the sand fraction at station I3 increased from 80.9% in January to 93.1% in July, while there were corresponding decreases in both the coarse and fine fractions between the surveys. At station I13, percent fines ranged from 11.2% in January to 0% in July, while the coarse and sand fractions both increased.

The sorting coefficient is calculated as the standard deviation (SD) in phi size units for each sample, therefore reflecting the range of particle sizes present, and is considered indicative of the level of disturbance (e.g., fluctuating or variable currents and sediment deposition) in an area. Sediments collected throughout the South Bay outfall region, including at stations located near the outfall, were well to poorly sorted (i.e., sorting coefficients ranging from 0.48 to 1.68; Table 4.1). The sediments most likely exposed to higher levels of disturbance (i.e., with the highest sorting coefficients) occurred at station I28 during both the January and July surveys (Appendix C.4).

Indicators of Organic Loading

There was no evidence of organic enrichment that could be associated with wastewater discharge in South Bay sediments during 2010. Although detection rates for TN, TOC, and sulfides were high (i.e., ≥89%; Table 4.1), concentrations of these organic indicators were generally similar to values measured between 1995–1998 prior to the onset of discharge (Figure 4.3). In addition, TN and TOC concentrations were significantly correlated with the proportion of fine sediments in each sample (Table 4.2, Figure 4.4A). TN ranged from 0.007 to 0.044% wt, and was highest at station I28 during both surveys (Appendix C.6). TOC concentrations

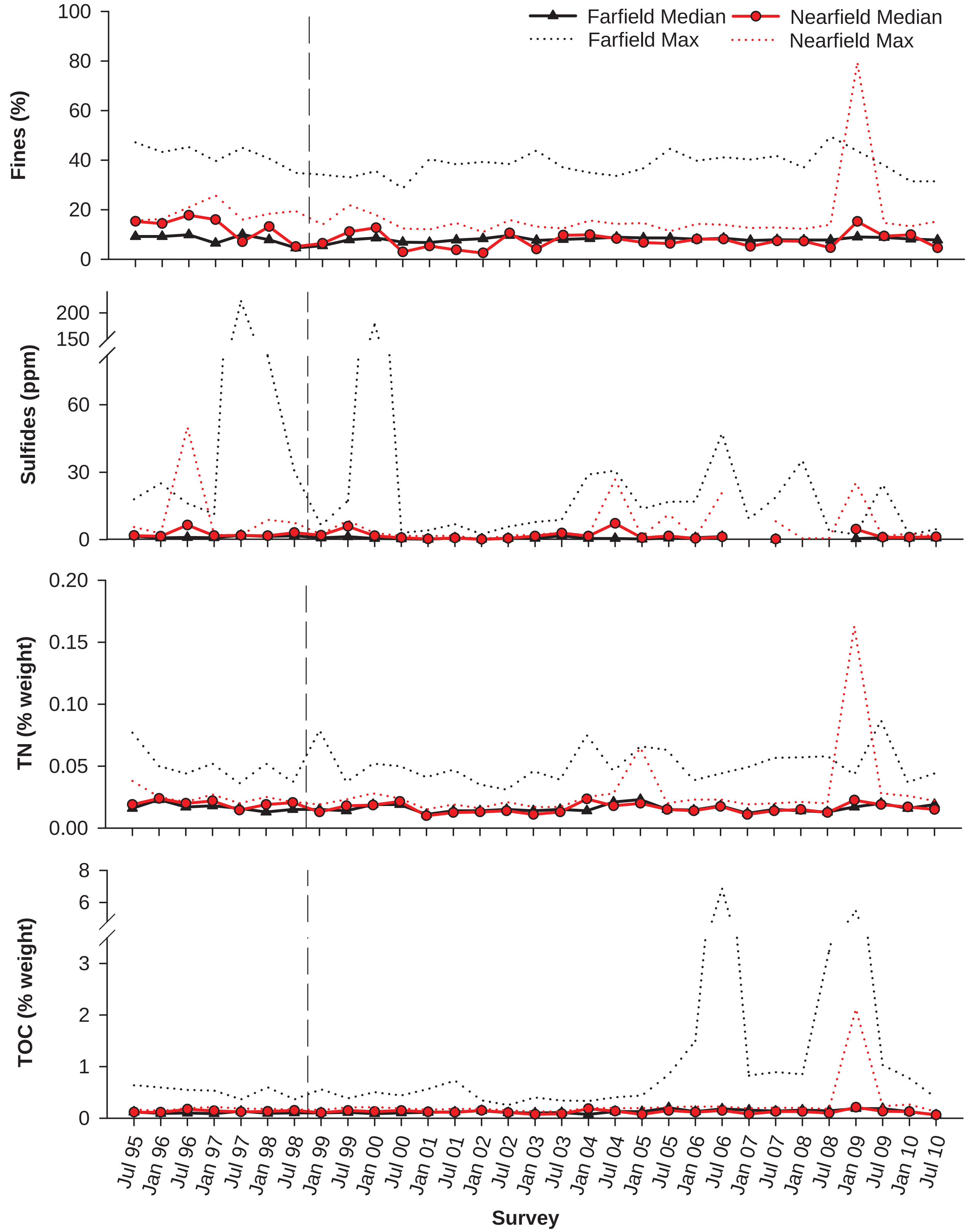


Figure 4.3

Particle size and organic indicator data from SBOO benthic stations sampled between 1995 and 2010. Parameters include: percent fines (Fines); sulfides; TN; TOC. Data are expressed as median and maximum values of all farfield ($n = 23$) and nearfield ($n = 4$) samples. Breaks in data lines represent surveys where the median or maximum value was below detection limits. Dashed lines indicate onset of discharge from the SBOO.

Table 4.2

Results of Spearman rank correlation analyses of percent fines and sediment chemistry parameters from SBOO benthic samples in 2010. Shown are analytes which had correlation coefficients $r_s(54) \geq 0.70$. For all analyses, $p < 0.001$. The strongest correlations with organic indicators and trace metals are illustrated graphically in Figure 4.4 below.

Analyte	r_s
Organic Indicators (% weight)	
Total Nitrogen	0.88
Total Organic Carbon	0.84
Trace Metals (ppm)	
Aluminum	0.86
Barium	0.83
Copper	0.70
Manganese	0.84
Nickel	0.91
Zinc	0.87

ranged from 0.014 to 0.769% wt throughout the year. The maximum TOC concentration in 2010 occurred at station I28 in January and slightly exceeded the pre-discharge maximum (0.638% wt) for this compound. TOC at this station was lower in July (0.395% wt). In contrast to TN and TOC, sulfides did not covary with percent fines. Concentrations of this organic indicator ranged from 0.16 to 4.72 ppm (Appendix C.6), with the highest concentrations (>4.0 ppm) occurring in samples from stations I27, I30, and I33 in July.

Trace Metals

Aluminum, barium, chromium, iron, lead, manganese, nickel and zinc were detected in all sediment samples collected in the SBOO region during 2010 (Table 4.1). Arsenic and copper also

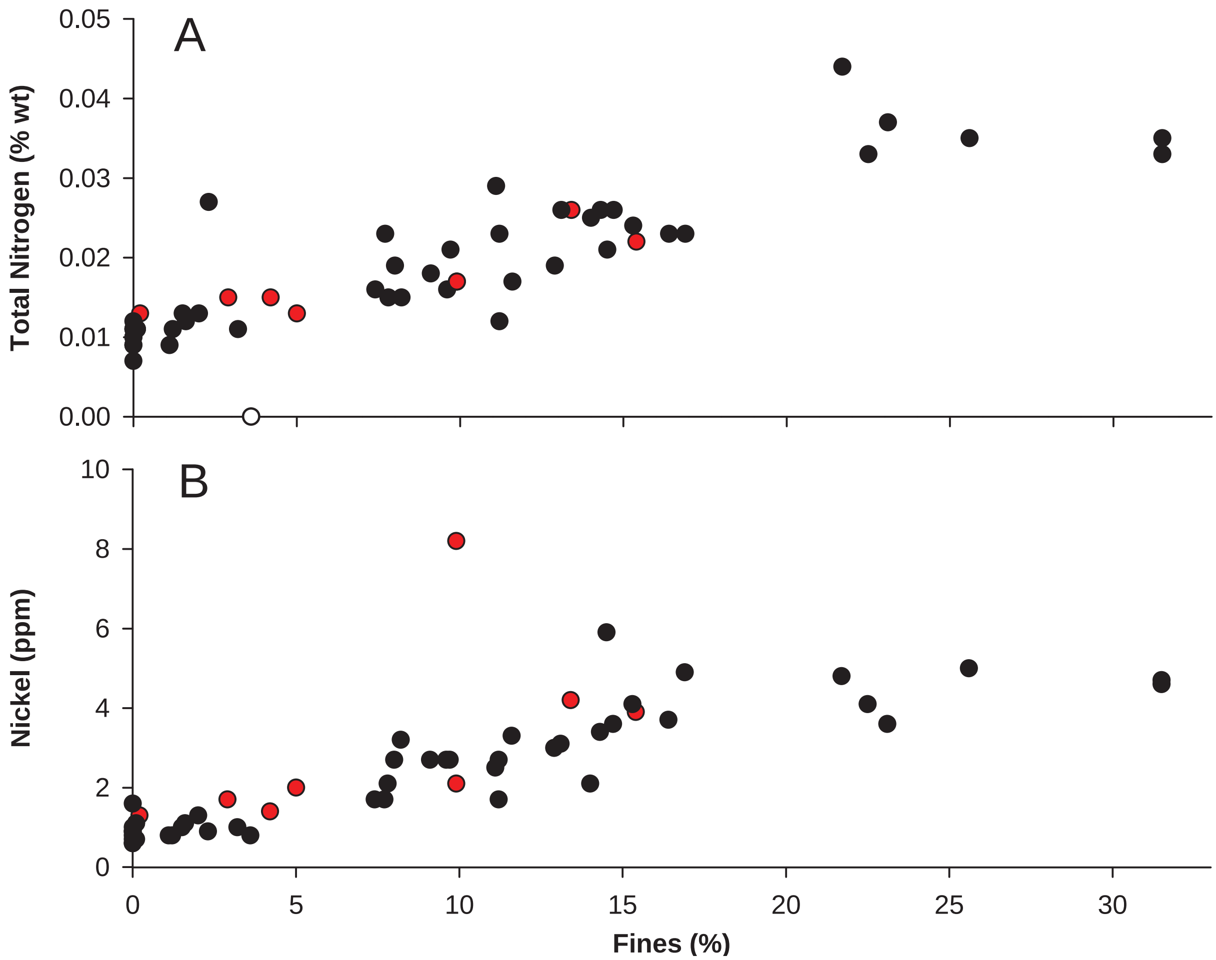


Figure 4.4

Scatterplot of percent fines and concentration of (A) total nitrogen and (B) nickel in SBOO sediments in 2010. Samples collected from nearfield stations are indicated in red. Open circles indicate samples with analyte concentrations below the method detection limit.

occurred frequently, in more than 90% of samples. In contrast, antimony, cadmium, mercury and tin were detected in less than 70% of the samples, while beryllium, silver, and thallium were detected very rarely (<10%), and selenium was not detected at all. Concentrations of each metal were below both the ERL and ERM thresholds. In addition, there were no discernible patterns relative to the outfall (Appendix C.7). Instead, the concentrations for several metals were significantly correlated with the proportion of fine particles (Table 4.2). This trend was particularly pronounced for nickel (Figure 4.4B). However, the maximum concentrations of several metals (i.e., chromium, iron, manganese, nickel, tin, and zinc) were detected at station I12 during January despite relatively low percent fines (9.9%) (Table 4.1, Appendix C.7). Finally, most metal concentrations in 2010 were below values reported prior to discharge. The only exception occurred in sediments from station I27 in January, where the concentration of cadmium (0.43 ppm) was slightly higher than pre-discharge (0.41 ppm). Cadmium was not detected at all at this station in July.

Pesticides

Chlorinated pesticides were detected in up to 26% of the SBOO sediment samples collected in 2010 (Table 4.1, Appendix C.8). As with the various trace metals, pesticide concentrations did not appear to be associated with wastewater discharge. Total DDT (primarily p,p-DDE; Appendix C.3) was the most prevalent pesticide, occurring in sediments from 12 of 27 stations at concentrations ranging from 47 to 1100 ppt. The maximum concentrations of tDDT were detected at station I29 during both surveys. All DDT concentrations were below values reported pre-discharge, as well as the ERL biological threshold for this contaminant. Another pesticide, hexachlorobenzene (HCB), was detected in 20% of samples, at a total of 11 stations, with values ranging from 40 to 220 ppt. The two highest HCB concentrations occurred at stations I12 and I14 in January; however this pesticide was not detected at all during July.

PAHs and PCBs

PAHs were not detected in sediment samples collected during 2010 (Table 4.1). Similarly, PCBs were rarely detected, occurring at a single station (I28) located over 9 km from the outfall. Total PCB concentrations were 290 ppt at this station in January and 74 ppt in July (Appendix C.8). PCB 153/168 was detected at this station during both surveys, while the January sample also included the congeners PCB 138 and PCB 149.

Discussion

Sediment particle size distribution at SBOO stations sampled in 2010 was similar to that seen historically (Emery 1960, MBC-ES 1988) and in recent survey years (City of San Diego 2007–2010). Sands composed the largest fraction in all samples, with the amounts of coarser and finer particles being variable among sites. There was no evident spatial relationship between sediment particle size and proximity to the outfall discharge site, nor has there been any substantial increase in fine sediments at nearfield stations or throughout the region since wastewater discharge began in 1999. Instead, the diversity of these sediments reflects multiple geologic origins and complex patterns of transport and deposition. In particular, the presence of red relict sands at some stations (e.g., I3, I6, I7, I13, I20, I21) is indicative of minimal deposition of recent sediments to these areas. However, several other stations (e.g., I27, I29, I30, I31, I33, I34, I35) are located near or within an accretion zone for sediments moving within the Silver Strand littoral cell (MBC-ES 1988, Patsch and Griggs 2007). The higher proportions of fine sands, silts, and clays at some of these stations are likely associated with the transport of fine materials originating from the Tijuana River, the Silver Strand beach, and to a lesser extent from San Diego Bay (MBC-ES 1988). In addition, SBOO sediments ranged from well to poorly sorted in 2010, further emphasizing the diverse conditions within the region. Well-sorted sediments (i.e., SD $\leq$ 0.5 phi) are composed of particles of similar size and are indicative of areas subject to consistent, moderate currents. In contrast, poorly sorted sediments (i.e., SD $\geq$ 1.0 phi) typically indicate areas of fluctuating weak to violent currents or rapid deposition (e.g., dredged material dumping) that often result in highly variable or patchy particle size distributions (Folk 1980). In general, sediment composition has been highly diverse and variable throughout the South Bay outfall region since sampling first began in 1995 (City of San Diego 2000).

Various indicators of organic loading, trace metals, chlorinated pesticides, and PCBs were detected in sediment samples collected from SBOO benthic stations during 2010. There were no spatial patterns to indicate an impact of the ocean outfall on sediment chemistry as concentrations of most contaminants at nearfield stations were similar to those at stations located further away. Instead, concentrations of TOC, TN, and several metals were generally higher at sites characterized by finer sediments. This pattern is consistent with that found in other studies, in which the accumulation of fine particles has been shown to greatly influence the organic and trace metal content of sediments (Eganhouse and Venkatesan 1993). Overall, concentrations of these contaminants were highly variable, similar to particle size distribution, and within the range of predischarge values for the SBOO region (City of San Diego 2000). Only two analytes (i.e., TOC and cadmium) were detected above pre-discharge maximum values, and these slightly higher concentrations occurred only in the January survey. In addition, there were no exceedances of either the ERL or ERM biological thresholds in 2010, indicating a lack of chemical contamination.

In summary, sediment conditions in the South Bay outfall region were diverse in 2010, although temporal differences in the particle size distributions at individual stations were minimal. Generally, sediment particle size patterns in the region are indicative of a diverse geologic history and complex transport patterns along this section of the coast. There was no evidence of fine-particle loading related to wastewater discharge in 2010. Likewise, contaminant concentrations at nearfield stations were within the range of variability throughout the SBOO region and do not appear enriched. The quality of sediments in the South Bay outfall region was similar in 2010 to previous survey years, and overall concentrations of all chemical analytes remained relatively low compared to many other coastal areas off southern California (Schiff and Gossett 1998, Noblet et al. 2003, Schiff et al. 2006, Maruya and Schiff 2009).

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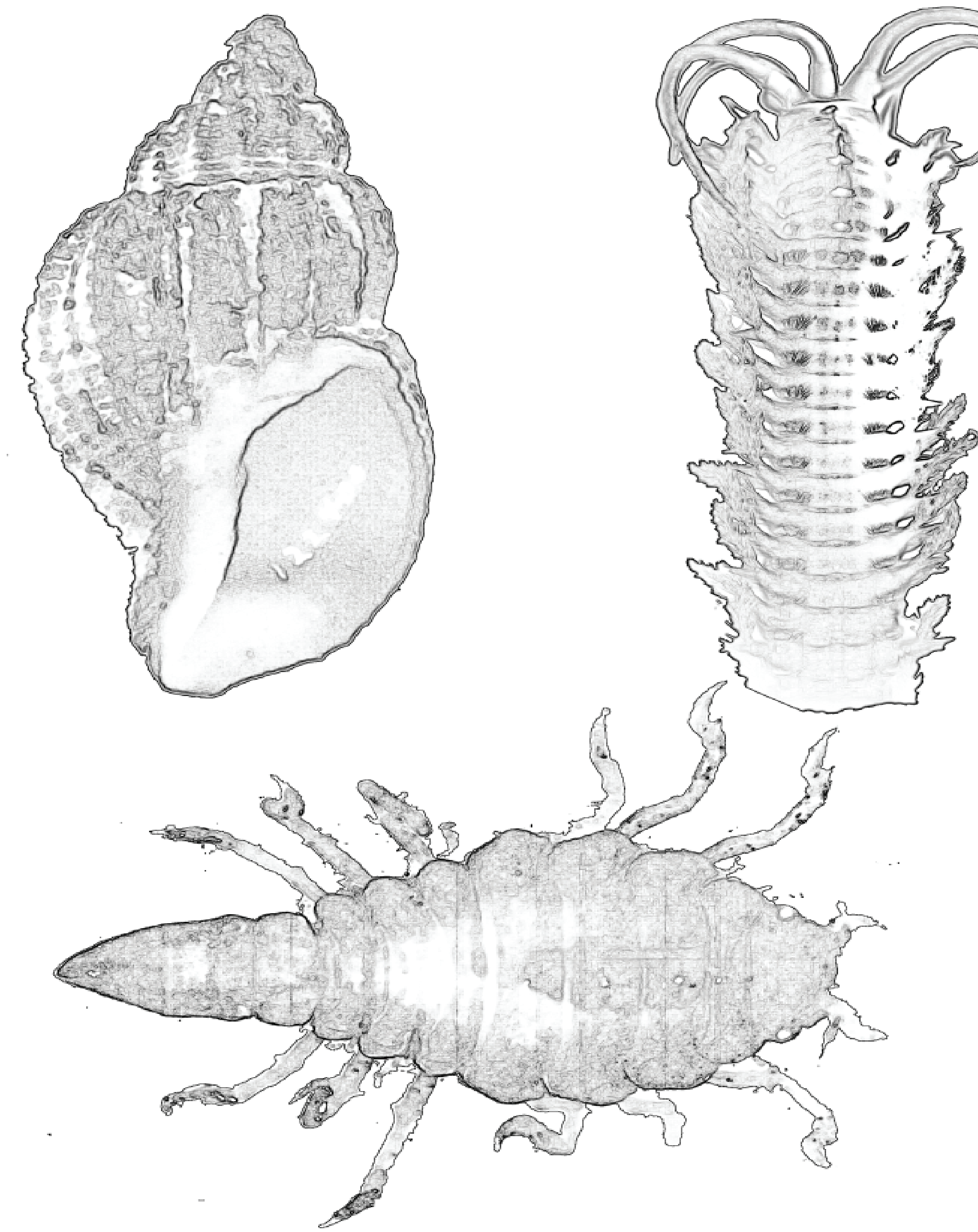
Chapter 5
Macrobenthic Communities



Chapter 5. Macrobenthic Communities

INTRODUCTION

Benthic macroinvertebrates along the coastal shelf of southern California represent a diverse faunal community that is important to the marine ecosystem (Fauchald and Jones 1979, Thompson et al. 1993a, Bergen et al. 2001). These animals serve vital ecological functions in wide ranging capacities (Snelgrove et al. 1997). For example, some species decompose organic material as a crucial step in nutrient cycling; other species filter suspended particles from the water column, thus affecting water clarity. Many species of benthic macrofauna also are essential prey for fish and other organisms.

Human activities that impact the benthos can sometimes result in toxic contamination, oxygen depletion, nutrient loading, or other forms of environmental degradation. Certain macrofaunal species are sensitive to such changes and rarely occur in impacted areas, while others are opportunistic and can persist under altered conditions (Gray 1979). Because various species respond differently to environmental stress, monitoring macrobenthic assemblages can help to identify anthropogenic impact (Pearson and Rosenberg 1978, Bilyard 1987, Warwick 1993, Smith et al. 2001). Also, since many animals in these assemblages are relatively stationary and long-lived, they can integrate the effects of local environmental stressors (e.g., pollution or disturbance) over time (Hartley 1982, Bilyard 1987). Consequently, the assessment of benthic community structure is a major component of many marine monitoring programs, which are often designed to document both existing conditions and trends over time.

Overall, the structure of benthic communities may be influenced by many factors including depth, sediment composition and quality (e.g., grain size distribution, contaminant concentrations), oceanographic conditions (e.g., temperature, salinity, dissolved oxygen, ocean currents), and biological factors (e.g., food availability, competition, predation). For example, benthic assemblages on the coastal shelf of southern California typically vary along sediment particle size and/or depth gradients (Bergen et al. 2001). Therefore, in order to determine whether changes in community structure are related to human impacts, it is necessary to have an understanding of background or reference conditions for an area. Such information is available for the monitoring area surrounding the South Bay Ocean Outfall (SBOO) and the San Diego region in general (see City of San Diego 1999, 2010, Ranasinghe et al. 2003, 2007).

This chapter presents analyses and interpretations of the macrofaunal data collected in 2010 at fixed stations surrounding the SBOO, including comparisons of the different soft-bottom macrofaunal assemblages in the region and descriptions of benthic community structure. The primary goals are to: (1) identify possible effects of wastewater discharge on local macrofaunal communities, (2) determine the presence or absence of biological impacts near the discharge site, and (3) identify any spatial or temporal trends in benthic community structure in the region.

Materials and Methods

Collection and Processing of Samples

Samples of benthic macroinvertebrates were collected at 27 established stations surrounding the SBOO located along the 19, 28, 38, or 55-m depth contours during January and July 2010 (Figure 5.1). Four of these stations are considered to represent "nearfield" conditions (i.e., I12, I14, I15, I16) and are located less than 1000 m from the wye or diffuser legs in order to assess possible ecosystem impacts to the area immediately adjacent the outfall. All other stations are referred to as "farfield."

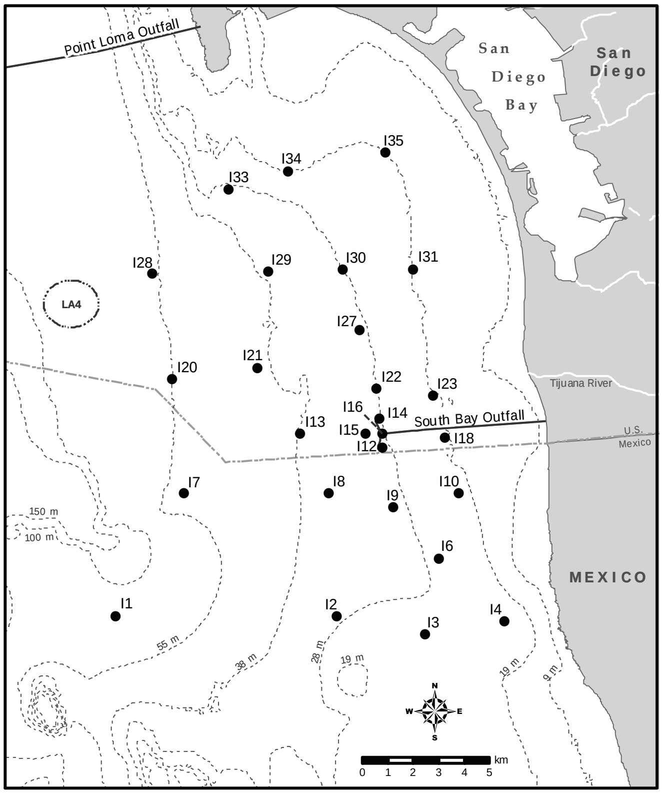


Figure 5.1
Benthic station locations sampled for the South Bay Ocean Outfall Monitoring Program.

Two replicate samples for benthic community analyses were collected per station during each survey using a double 0.1-m^2 Van Veen grab. One of the two grabs from the first cast was used for macrofauna, while the adjacent grab was used for sediment quality analysis (see Chapter 4); a second grab for macrofauna was then collected from a subsequent cast. To ensure consistency of grab samples, criteria established by the United States Environmental Protection Agency (USEPA) were followed to standardize sample disturbance and depth of penetration (USEPA 1987). All samples were sieved aboard ship through a 1.0-mm mesh screen, and organisms retained on the screen were collected and relaxed for 30 minutes in a magnesium sulfate solution before fixing in buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol. All animals were sorted from the debris into major taxonomic groups by a subcontracted laboratory and then identified to species or the lowest taxon possible and enumerated by City of San Diego marine biologists.

Data Analyses

The following community structure parameters were calculated and summarized for each station per 0.1-m^2 grab: species richness (number of species), abundance (number of individuals), Shannon diversity index (H'), Pielou's evenness index (J'), Swartz dominance (minimum number of taxa whose combined abundance accounts for 75% of the individuals in a sample; Swartz et al. 1986, Ferraro et al. 1994), and the benthic response index (BRI) of Smith et al. (2001). Additionally, the total or cumulative number of species over all grabs was calculated for each station.

To examine spatio-temporal patterns in the overall similarity of benthic macrofaunal assemblages, analyses were performed on grab-averaged data using PRIMER software (Clarke 1993, Warwick 1993, Clarke and Gorley 2006). These analyses included classification (cluster analysis) by hierarchical agglomerative clustering with group-average linking and ordination by non-metric multidimensional scaling (nMDS). Species abundance data were square-root transformed and the Bray-Curtis measure of similarity was used as the basis for classification. Similarity profile (SIMPROF) analysis was used to confirm non-random structure of the dendrogram (Clarke et al. 2008). Similarity percentages (SIMPER) analysis was used to identify which species accounted for differences between cluster groups as well as the specific species that typified each cluster group. Patterns in the distribution of the different assemblages were compared to environmental variables by overlaying the physico-chemical data onto nMDS plots based on the biotic data (Field et al. 1982, Clarke and Ainsworth 1993).

Results

Community Parameters

Species richness
A total of 736 taxa (mostly species) were identified during the 2010 SBOO surveys. Of these, 190 (~26%)

Table 5.1

Summary of macrofaunal community parameters for SBOO benthic stations sampled during 2010. Tot Spp = cumulative no. species for the year; SR = species richness (no. species/0.1 m^2); Abun = abundance (no. individuals/0.1 m^2); H' = Shannon diversity index; J' = evenness; Dom = Swartz dominance; BRI = benthic response index; * = nearfield stations. Data are expressed as annual means ($n = 4$) except Tot Spp ($n = 1$).

Station		Depth	Tot Spp	SR	Abun	H'	J'	Dom	BRI
19-m Stations									
I35		19	150	78	290	3.8	0.88	28	29
I34		19	91	37	470	1.7	0.48	5	9
I31		19	141	61	251	2.8	0.69	14	20
I23		21	178	75	233	3.7	0.86	27	21
I18		19	119	55	280	2.7	0.66	11	20
I10		19	127	54	185	3.1	0.78	17	19
I4		18	112	41	157	3.0	0.81	14	7
28-m Stations									
I33		30	163	82	318	3.6	0.82	25	24
I30		28	157	73	247	3.7	0.86	27	23
I27		28	145	65	184	3.5	0.85	25	23
I22		28	209	93	751	3.0	0.64	22	22
I14*		28	161	75	301	3.2	0.75	21	24
I16*		28	180	82	366	3.1	0.69	21	25
I15*		31	135	58	996	1.3	0.31	2	18
I12*		28	207	86	648	2.7	0.59	15	23
I9		29	204	99	418	3.8	0.84	30	22
I6		26	107	49	1490	1.5	0.39	5	10
I2		32	84	38	199	2.3	0.64	7	15
I3		27	90	38	213	2.6	0.73	10	9
38-m Stations									
I29		38	242	124	474	4.1	0.84	39	19
I21		41	121	55	222	3.3	0.83	17	8
I13		38	118	48	152	3.1	0.81	17	9
I8		36	117	51	343	2.4	0.62	8	20
55-m Stations									
I28		55	295	148	485	4.5	0.90	56	13
I20		55	137	57	219	3.2	0.81	17	5
I7		52	124	53	136	3.5	0.89	21	7
I1		60	155	74	237	3.7	0.85	27	12
All Grabs	Mean		151	68	380	3.1	0.73	19	16
	Standard Error		9	3	40	0.1	0.02	1	1
	Minimum		84	22	58	0.5	0.12	1	1
	Maximum		295	163	3216	4.6	0.93	60	31

represented rare taxa that were recorded only once. Mean values of species richness ranged from a low of 37 taxa per 0.1 m^2 at station I34 to a high of 148 taxa per 0.1 m^2 at station I28 (Table 5.1). Overall species richness dropped compared to last year, with 10% fewer taxa collected in 2010 versus 2009. Although species richness varied spatially, there were no apparent patterns relative to distance from the discharge site (Table 5.1, Figure 5.2A).

Macrofaunal abundance

A total of 41,051 macrofaunal individuals were identified in 2010, with mean abundance values ranging from 136 to 1490 animals per 0.1 m^2 (Table 5.1). The greatest number of animals occurred at station I6, while the fewest animals occurred at station I7. Overall, there was a 7% increase in total macrofaunal abundance

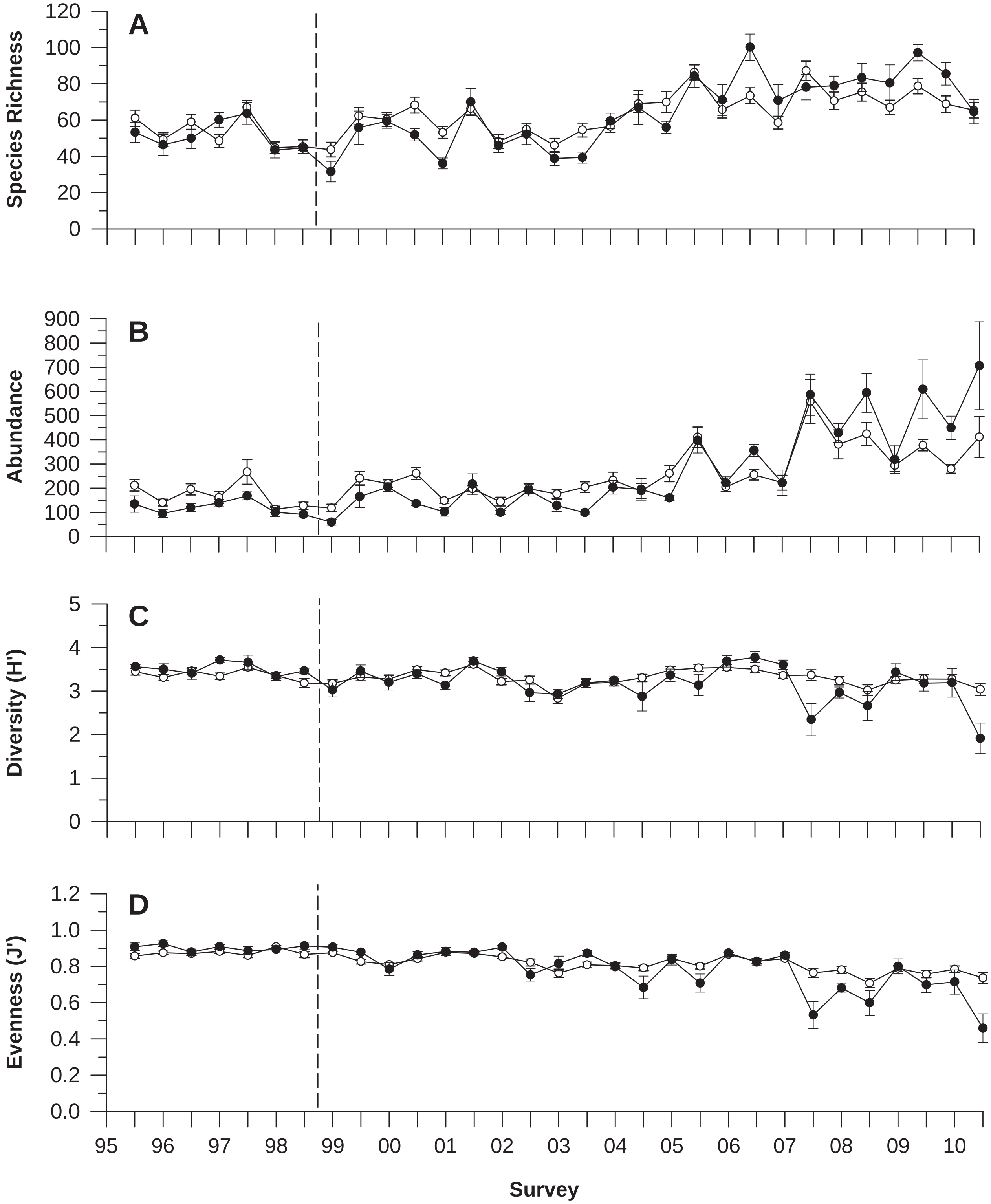


Figure 5.2

Macrofaunal community parameters at SBOO benthic stations from 1995 to 2010. Parameters include: Species richness (no. of taxa); Abundance (no. of animals); Diversity = H'; Evenness = J'; Swartz dominance index; BRI = Benthic response index. Data are expressed as means ± standard error per 0.1 m^2 pooled over nearfield stations (filled circles; *n* = 8) versus farfield stations (open circles; *n* = 46) for each survey. Dashed line indicates onset of discharge from the SBOO.

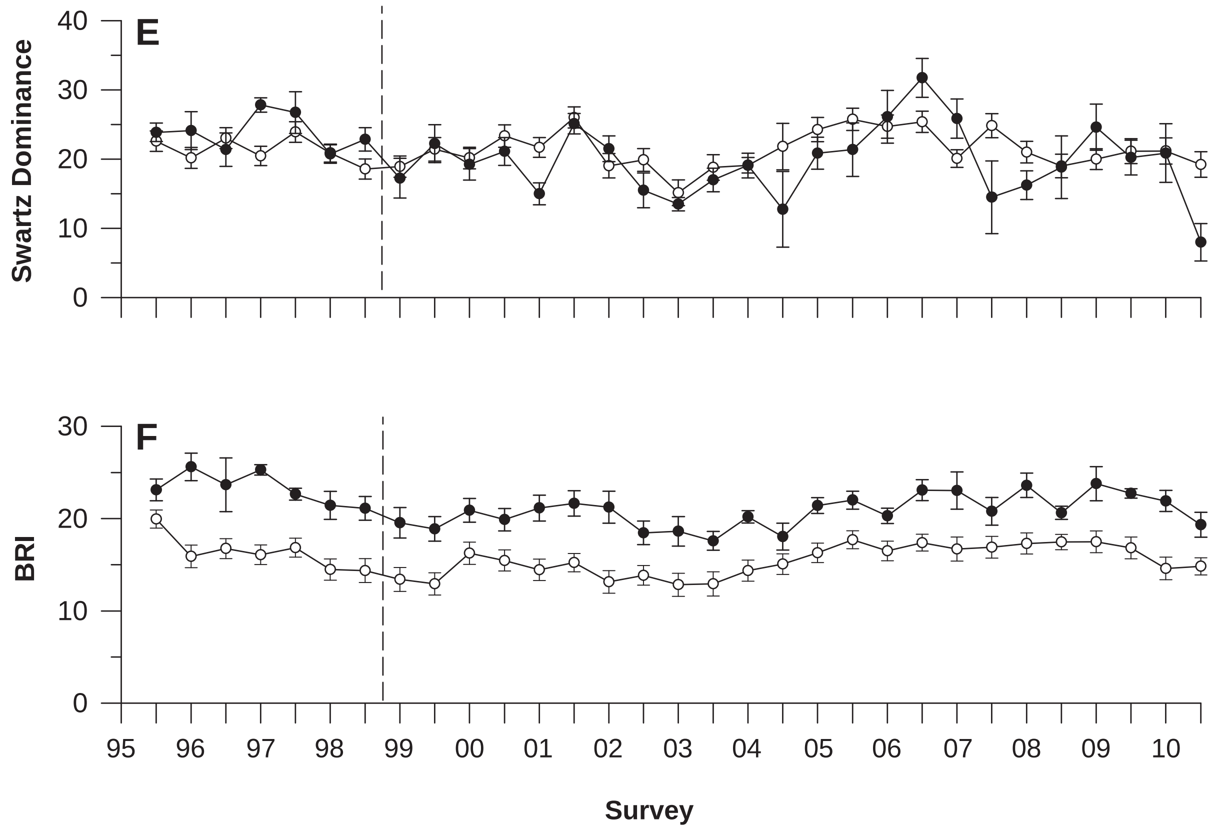


Figure 5.2 *continued*

between 2009 and 2010 (Figure 5.2B), with the greatest change occurring at station I6 (City of San Diego 2010). The mean abundance for all nearfield stations has increased in recent years relative to farfield stations (Figure 5.2B). In 2010, the increased nearfield abundance and associated variation relative to farfield stations was likely due to large numbers of *Spiophanes norrisi* collected at stations I12 and I15 in July.

Species diversity and dominance

Average species diversity (H') ranged from 1.3 at station I15 to 4.5 at station I28 during 2010 (Table 5.1). Historically, H' values have mostly been similar between nearfield and farfield stations. However, average H' values at nearfield stations sampled in July 2010 were low compared to farfield stations (1.9 vs. 3.0, respectively) (Figure 5.2C). Evenness (J') compliments diversity, with higher J' values (on a scale of 0–1) indicating that species are more evenly distributed (i.e., not dominated by a few highly abundant species). During 2010, J' values averaged between 0.31 at station I15 and 0.90 at station I28 with spatial patterns similar to those for diversity (Figures 5.2C, D). Swartz dominance values averaged from 2 to 56 species per station during the year (Table 5.1). This range reflects the dominance of a few species at some sites (e.g., low values at stations I15, I6, and I34) versus other stations where many taxa contributed to the overall abundance (e.g., high values at stations I28 and I29).

Benthic response index

Benthic response index (BRI) values in 2010 averaged from 5 at station I20 to 29 at station I35, while BRI values for individual grabs ranged from 1 to 31 (Table 5.1). BRI values below 25 are considered indicative of reference conditions, while values between 25–34 represent “a minor deviation from reference conditions” that should be confirmed by additional sampling (Smith et al. 2001). Station I35 was the only station with an annual mean BRI value above 25. This station, located on the 19-m depth contour near the mouth of the San Diego Bay, had an annual mean BRI value of 31 in 2009. All nearfield stations had annual BRI means at or below 25 in

Table 5.2

Percent composition of species and abundance by major taxonomic group (phylum) for SBOO benthic stations sampled during 2010. Data are expressed as annual means (range) for all stations combined; $n=27$.

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	48 (38–58)	72 (55–95)
Arthropoda (Crustacea)	21 (14–27)	12 (2–23)
Mollusca	16 (10–24)	8 (1–18)
Echinodermata	6 (2–11)	4 (1–11)
Other Phyla	9 (6–13)	4 (1–9)

2010. Along with I35, three other stations contained individual grabs with BRI values >25 (I16, I27, and I30). As in previous years (including the pre-discharge period), mean BRI values at the four nearfield stations were higher than mean values for all the farfield stations combined (Figure 5.2F).

Dominant Species

Macrofaunal communities in the SBOO region were dominated by polychaete worms in 2010, which accounted for 48% of all species collected (Table 5.2). Crustaceans accounted for 21% of species reported, while molluscs, echinoderms, and all other taxa combined accounted for the remaining 16%, 6%, and 9%, respectively. Polychaetes were also the most numerous animals, accounting for 72% of the total abundance. Crustaceans accounted for 12% of the animals collected, molluscs 8%, echinoderms 4%, and the remaining phyla 4%. Overall, the above distributions were very similar to those observed in 2009 (City of San Diego 2010).

Seven polychaetes (i.e., *Spiophanes norrisi* and *S. duplex*, Euclymeninae sp A, *Monticellina siblina*, *Scoloplos armiger* complex, *Onuphis* sp A, and *Sigalion spinosus*) and three crustaceans (i.e., *Ampelisca cristata cristata*, *Euphilomedes carcharodonta*, and *Foxiphalus obtusidens*) were among the 10 most abundant macroinvertebrates sampled during the year (Table 5.3). The most abundant species collected was the spionid *S. norrisi*, which occurred at 98% of the stations and averaged 162 individuals per sample. While *S. norrisi* was nearly ubiquitous in distribution, abundances at individual stations varied considerably (range: 6–2504). For example, five stations (I6, I15, I22, I34 and I12 in July) supported much higher abundances of this species than the other sites, with a combined total of 11,536 individuals. Overall, *S. norrisi* accounted for about 43% of the macrobenthic fauna sampled during 2010 and has become the most abundant species collected since monitoring began (Figure 5.3, Appendix D.1).

Few other macrobenthic species were as widely distributed as *S. norrisi* (Table 5.3), with only seven taxa occurring in at least 80% of the samples. However, many of the species collected in 2010 have been dominant in past years as well. For example, six of the most abundant species collected in 2010 (i.e., *S. norrisi*, *A. cristata cristata*, *S. duplex*, *E. carcharodonta*, Euclymeninae sp A, and *M. siblina*) were among the 10 most abundant taxa collected historically (Figure 5.3; Appendix D.1). In contrast, some species were found in relatively high abundances at a limited number of stations. For example, the oweniid polychaete *Myriochele gracilis* was collected at only two stations (I1 and I28) with mean abundances of 29 animals per 0.1 m^2 grab.

Classification of Macrobenthic Assemblages

Results of the ordination and cluster analyses discriminated six habitat-related macrobenthic assemblages (Figure 5.4). These assemblages (cluster groups A–F) varied in terms of species composition (i.e., specific taxa present) and the relative abundance of each species, and occurred at sites separated by different depths and/or sediment microhabitats (Figure 5.5). The SIMPROF procedure indicated statistically significant non-random structure among samples (Global test: $\pi=6.82$, $p<0.001$), and an nMDS ordination of the station/survey entities supported the validity of

Table 5.3

The 10 most abundant macroinvertebrates collected at the SBOO benthic stations during 2010. Abundance values are expressed as mean number of individuals per 0.1-m^2. Percent occurrence = percent of total samples where the species was collected.

Species	Higher Taxa	Abundance per Sample	Percent Occurrence
Spiophanes norrisi	Polychaeta: Spionidae	162.0	98
Spiophanes duplex	Polychaeta: Spionidae	9.9	80
Euclymeninae sp A	Polychaeta: Maldanidae	9.6	74
Monticellina siblina	Polychaeta: Cirratulidae	8.7	72
Scoloplos armiger complex	Polychaeta: Orbiniidae	2.7	91
Ampelisca cristata cristata	Crustacea: Amphipoda	2.4	82
Euphilomedes carcharodonta	Crustacea: Ostracoda	2.1	80
Onuphis sp A	Polychaeta: Onuphidae	1.8	80
Sigalion spinosus	Polychaeta: Sigalionidae	1.5	82
Foxiphalus obtusidens	Crustacea: Amphipoda	1.5	78

the selected cluster groups (Figure 5.4B). SIMPER analysis identified species that were characteristic, though not always the most abundant, within assemblages; a comparison of the most abundant taxa for each cluster group combined with SIMPER results is indicated in Table 5.4. A list of species identified by SIMPER as discriminating between individual cluster groups can be found in Appendix D.2. Overall, clusters were very similar and no single species strongly discriminated between groups. On average, 177 species contributed to 75% of the dissimilarity between any two cluster groups.

Cluster group A contains macrofaunal assemblages sampled in January and July at two stations located east of the outfall discharge site along the 55-m depth contour. This group of sites averaged 176 individuals and 55 taxa per 0.1 m^2. The three most characteristic species encountered were the ophiuroid *Ophiuroconis bispinosa*, the isopod *Eurydice caudata*, and the sabellid polychaete *Jasmineira* sp B. Sediments at these sites were coarse, composed of red relict sands with only 2% fines and had a total organic carbon (TOC) concentration of 0.1% weight (% wt).

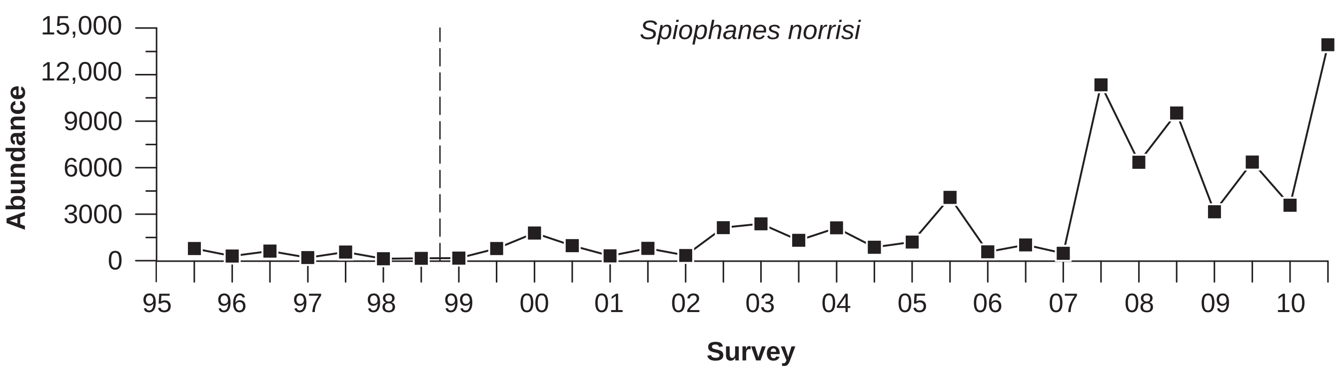


Figure 5.3

Total abundance per survey for *Spiophanes norrisi* at the SBOO benthic stations from 1995–2010. Dashed line indicates onset of wastewater discharge.

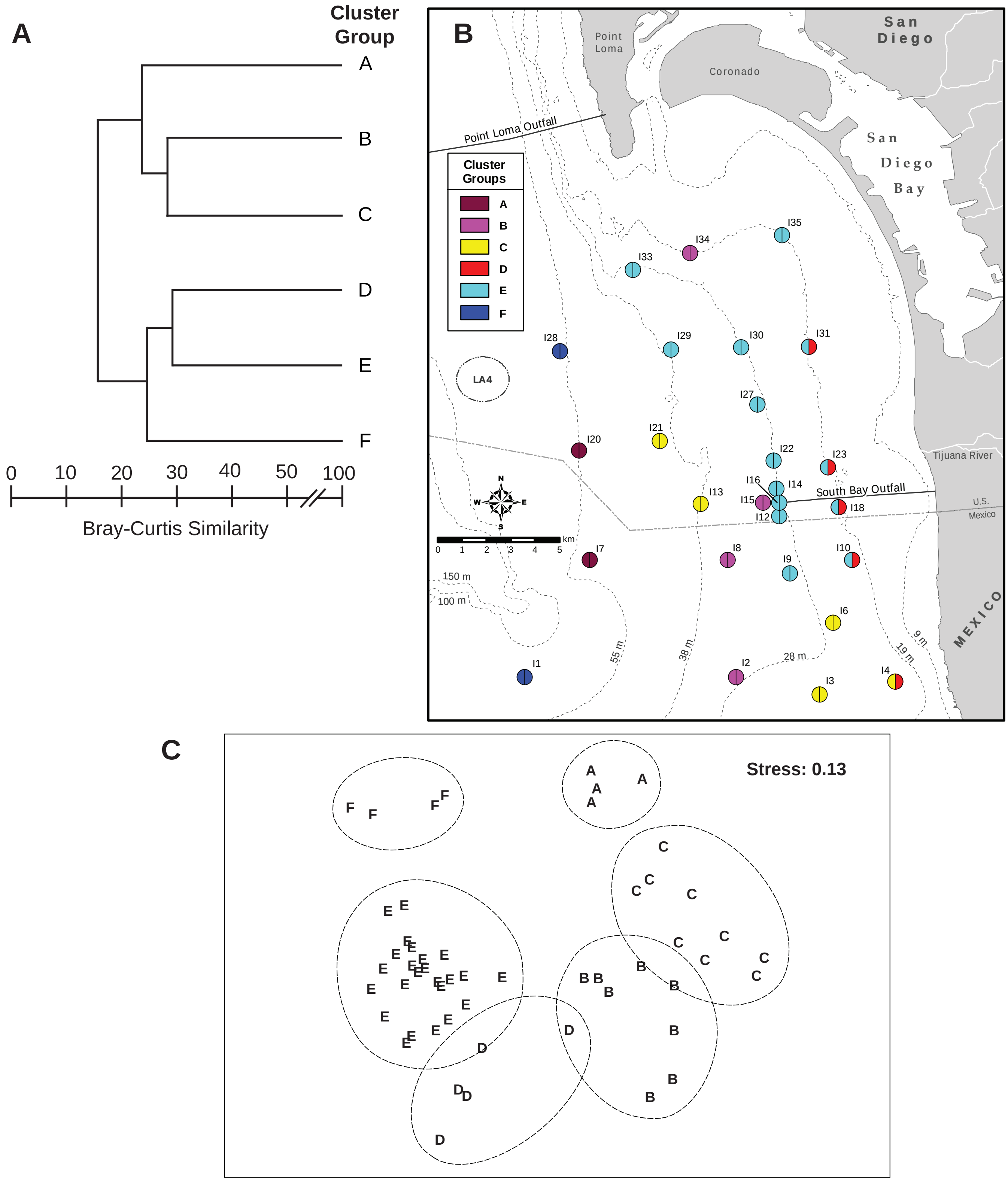


Figure 5.4

Results of multivariate analyses of macrofaunal abundance data for the SBOO benthic stations sampled during January and July 2010. Data are presented as: (A) cluster results; (B) spatial distribution of macrobenthic assemblages delineated by ordination and classification analyses (left half of circle represents cluster group affiliation for the January survey; right half represents the July survey); (C) nMDS ordination based on square-root transformed abundance data for each station/survey entity. Dashed ellipses enclose cluster groups within a similarity of 29.5%.

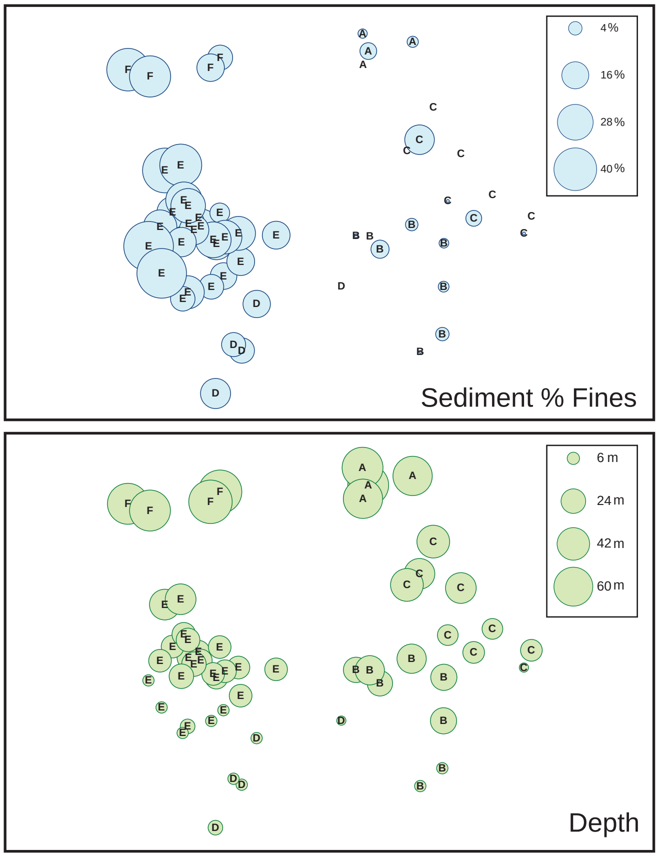


Figure 5.5

Ordination (nMDS) of SBOO benthic stations sampled during winter and summer 2010. Cluster groups A–F are superimposed on station/surveys. Percentages of fine particles in the sediments and station depth are further superimposed as circles that vary in size according to the magnitude of each value. Plots indicate associations of benthic assemblages with habitats that differ in sediment grain size and depth. Stress = 0.13.

Cluster group B contains shallow-shelf macrofaunal assemblages that typically occurred between the 28 and 38-m depth contours. Sites in this group averaged 46 taxa and 502 individuals per 0.1 m^2, the latter being the highest abundance among all cluster groups. The glycerid polychaete *Glycera oxycephala* was characteristic, as were the orbiniid polychaete *Scoloplos armiger* and the sand dollar *Dendraster terminalis*. The sediments associated with this assemblage were mostly sand with some shell hash and 1% fines, and with TOC values of 0.1% wt on average.

Cluster group C (five sites) includes assemblages that occurred mostly south or east of the outfall at depths between 19–38 m. These assemblages averaged 45 taxa and 472 organisms per 0.1 m^2. *Scoloplos armiger*, *Dendraster terminalis* and the spionid polychaete *Spio maculata* were the three most characteristic species found at these sites. The habitat was characterized by mixed but coarse sediments, especially red relict sand, with TOC values that averaged 0.1% wt.

Cluster group D represents macrofaunal assemblages from the shallowest sites sampled during the July survey that occurred along the 19-m depth contour. Abundance averaged 219 individuals and species richness averaged 54 taxa per 0.1 m^2. The three most characteristic species included the amphipod *Ampelisca cristata cristata*, the ampharetid polychaete *Ampharete labrops*, and the nemertean *Carinoma mutabilis*. Sediments at this site were relatively sandy with 8% fines and contained shell hash and organic debris. These sediments had an average TOC value of 0.1% wt.

Cluster group E contains macrobenthic assemblages from fourteen stations located along the 19 and 28-m depth contours, and represents the most geographically broad subset of sites found in any of the clusters. This shallow shelf assemblage averaged 83 taxa and 376 individuals per 0.1 m^2, with the bivalve *Tellina modesta*, the spionid *Spiophanes berkeleyorum*, and the maldanid Euclymeninae sp A being the most characteristic species recorded. The sediments associated with this assemblage were characterized by sand, some organic debris, and 14% fines with TOC values of 0.2% wt on average.

Cluster group F includes mid-shelf assemblages from two stations located near the 55-m depth contour, which bracket the sites in cluster group A. These sites averaged 361 individuals and 111 taxa per 0.1 m^2, the latter representing the highest species richness for the region. The three most characteristic species included the paronid polychaete *Aricidea* (*Acmira*) *simplex*, the thyasirid bivalve *Axinopsida serricata*, and the tanaid *Leptochelia dubia*. The sediments associated with this group were mixed, composed of 16% fines and some coarse black sand with TOC values of 0.4% wt on average.

Table 5.4

Description of cluster groups A–F defined in Figure 5.4. Data for percent fines, total organic carbon (TOC; % weight), depth (m), species richness, and infaunal abundance are expressed as mean values per 0.1-m^2 over all stations in each group. Bold values indicate taxa that were considered most characteristic of that group according to SIMPER analysis (i.e., greatest percentage contribution to within-group similarity).

	Group A	Group B	Group C	Group D	Group E	Group F
n	4	8	9	5	24	4
Percent Fines	2	1	2	8	14	16
Depth	54	30	31	19	27	58
TOC	0.1	0.1	0.1	0.1	0.2	0.4
Species Richness	55	46	45	54	83	111
Abundance	176	502	472	219	376	361

Taxa			**Mean Abundance**			
Mooreonuphis sp SD1	24.3	0.4	3.7			
Spiophanes norrisi	15.1	358.1	324.7	72.0	104.8	8.4
Mooreonuphis sp	11.5	0.6	4.1	0.9	0.1	0.4
Eurydice caudata	10.0	2.1	3.7	0.4	0.2	0.1
Ophiuroconis bispinosa	**10.0**	1.1	3.4		0.6	2.9
Lanassa venusta venusta	7.5	0.1	4.5		0.0	0.1
Euclymeninae sp A	4.5	0.3	0.3	3.0	**19.1**	6.8
Lumbrinerides platypygos	2.3	12.4	4.6	0.1	0.9	
Glycera oxycephala	1.6	**13.4**	1.3	0.8	1.5	0.1
Spio maculata	1.5	1.9	**12.9**		0.0	0.1
Ampharete labrops	0.8	3.1	1.5	**17.3**	2.1	0.4
Aricidea (*Acmira*) *simplex*	0.5		0.1		0.0	**12.6**
Amphiodia urtica	0.1	9.4	2.7	0.1	1.3	8.8
Pista estevanica	0.1	1.1			1.7	8.8
Spiophanes duplex	0.1	0.9	0.2	17.4	17.1	5.3
Monticellina siblina	0.1	0.8	0.1	2.8	17.4	5.8
Notomastus latericeus		12.8	0.3	1.2	4.6	0.5
Dendraster terminalis		**2.5**	**5.7**	2.0	0.0	
Mediomastus sp		0.7		6.6	5.8	2.3
Apoprionospio pygmaea		0.6		5.7	2.3	
Axinopsida serricata					0.3	**12.4**
Myriochele gracilis						29.3

Discussion

Benthic macrofaunal assemblages surrounding the SBOO were similar in 2010 to those encountered during previous years, including the period before initiation of wastewater discharge (City of San Diego 2000, 2010). Additionally, these assemblages were typical of those occurring in other sandy, shallow- and mid-depth habitats throughout the Southern California Bight (SCB) (Thompson et al. 1987, 1993b, City of San Diego 1999, Bergen et al. 2001, Ranasinghe et al. 2003, 2007, Mikel et al. 2007). For example, assemblages from cluster groups B, C and E contained high numbers of the spionid polychaete *Spiophanes norrisi*, a species commonly found in shallow-water environments with sandy sediments in the SCB (Bergen et al. 2001). These three groups represented sub-assemblages of the SCB benthos that differed in the relative abundances of dominant and co-dominant species. Such differences probably reflect variation in sediment structure, such as the presence or absence of red relict sands. Consistent with historical values, sediments in the shallow SBOO region generally were coarser south of the outfall relative to the more northern stations (see Chapter 4).

The group D assemblage contained fewer individuals of *Spiophanes norrisi* relative to the other shallow water groups B, C and E, likely because of the higher percentage of fines found at sites in group D. However, the fewest *S. norrisi* occurred at sites from mid-depth shelf habitats (i.e., cluster groups A and F), probably because these sites represent a transition between the shallow sandy sediments and finer mid-depth sediments characteristic of much of the SCB mainland shelf (Barnard and Ziesenhenne 1961, Jones 1969, Fauchald and Jones 1979, EcoAnalysis et al. 1993, Thompson et al. 1993a, Diener and Fuller 1995). The sediment composition at the sites that make up groups A and F are not typically associated with high *S. norrisi* abundances.

Results from PRIMER analyses revealed no clear spatial patterns relative to the South Bay outfall. Comparisons of the biotic data to the physico-chemical data suggest that macrofaunal distribution and abundance in the region varied primarily along depth and sediment gradients. Populations of *S. norrisi* collected during 2010 were the highest recorded for this polychaete since monitoring began in 1995. Consequently, the high numbers for this species influenced overall abundance values in the region during the past year. Patterns of region-wide abundance fluctuations over time appear to mirror historical patterns of this species, while temporal fluctuations in the populations of this and similar polychaete species (Appendix D.1) occur elsewhere in the region and may correspond to larger scale oceanographic conditions (Zmarzly et al. 1994). Overall, analyses of temporal patterns suggest that the benthic community in the South Bay outfall region has not been significantly impacted by wastewater discharge. For example, while species richness and total macrofaunal abundance were at or near historical highs during 2010, annual means at the four nearfield stations remained similar to those located further away (City of San Diego 2006–2010). Diversity and evenness values have also remained relatively stable since monitoring began in 1995, with some recent exceptions. For example, stations with high *S. norrisi* abundances in 2010 had relatively lower species diversity, evenness, and Swartz dominance values compared to other stations.

Benthic response index (BRI) values continue to be generally characteristic of assemblages from undisturbed habitats. Since monitoring began, mean BRI values at the four nearfield stations have been higher than values for all the farfield stations combined. This pattern has remained consistent over time, including the pre-discharge period. Because this pattern was not affected by the onset of wastewater discharge, it appears that differences in BRI values could be caused by a depth effect inherent with the BRI. For example, Smith et al. (2001) found a pattern of lower index values at mid-depth stations versus shallower or deeper stations.

Anthropogenic impacts are known to have spatial and temporal dimensions that can vary depending on a range of biological and physical factors. Such impacts can be difficult to detect, and specific effects of the SBOO discharge on the local macrobenthic community could not be identified during 2010. Furthermore, benthic invertebrate populations exhibit substantial spatial and temporal variability that may mask the effects of any disturbance event (Morrisey et al. 1992a, b, Otway 1995). Although some changes have occurred near the SBOO over time, benthic assemblages in the area remain similar to those observed prior to discharge and to natural indigenous communities characteristic of similar habitats on the southern California continental shelf.

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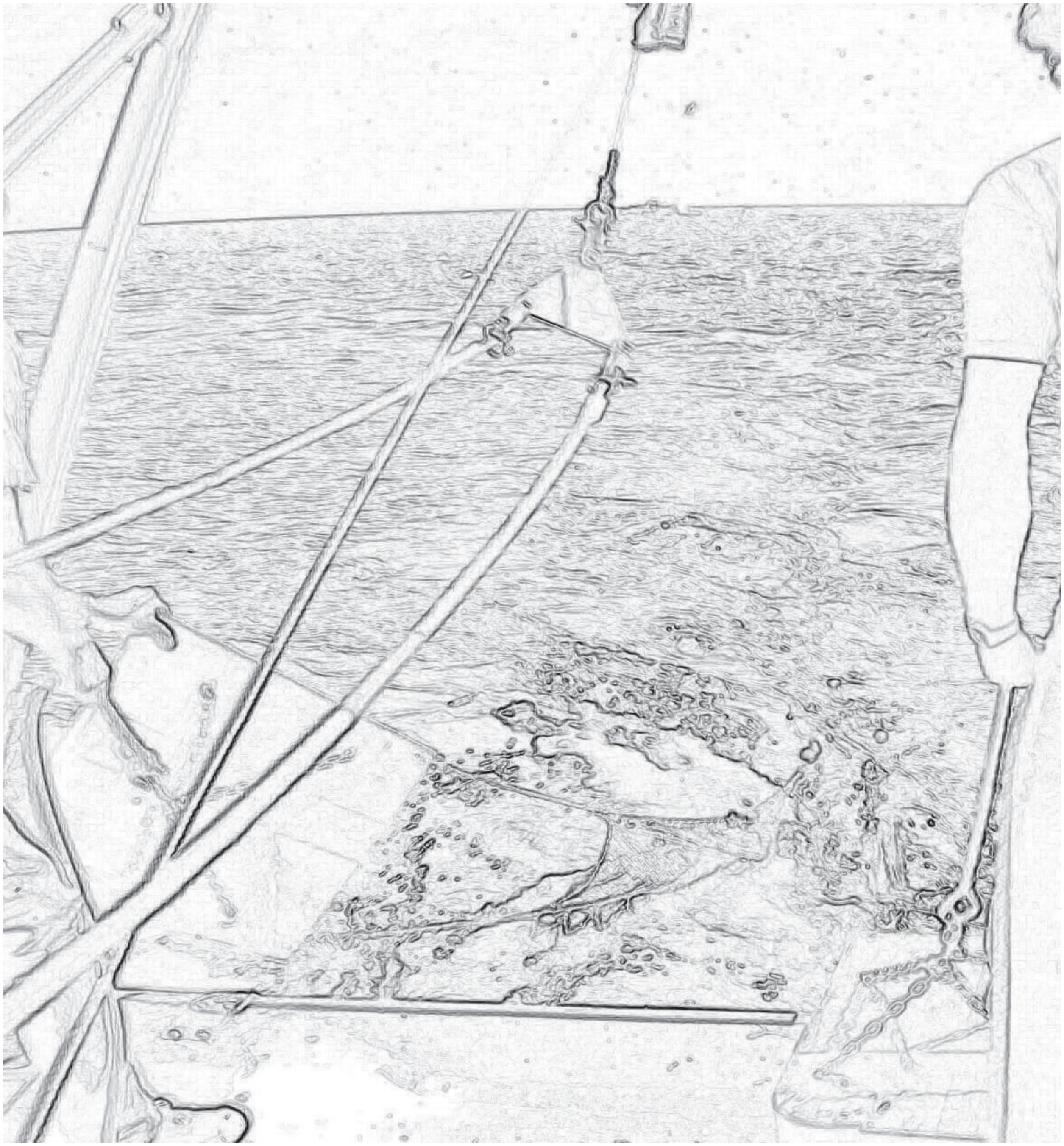
Chapter 6
Demersal Fishes
and Megabenthic Invertebrates



Chapter 6. Demersal Fishes and Megabenthic Invertebrates

INTRODUCTION

Demersal (bottom dwelling) fishes and relatively large (megabenthic), mobile invertebrates are collected and analyzed for the South Bay Ocean Outfall (SBOO) monitoring program to evaluate possible effects of wastewater discharge on their communities. These fishes and invertebrates are conspicuous members of continental shelf habitats and are therefore important to the ecology of the southern California coastal shelf, serving vital functions in wide ranging capacities. More than 100 species of demersal fishes inhabit the Southern California Bight (SCB), while the megabenthic invertebrate fauna consists of more than 200 species (Allen 1982, Allen et al. 1998, 2002, 2007). For the region surrounding the SBOO, the most common trawl-caught fishes include speckled sanddab, hornyhead turbot, California halibut, and California lizardfish. Common trawl-caught invertebrates include various echinoderms (e.g., sea stars, sea urchins, sea cucumbers, sand dollars), crustaceans (e.g., crabs, shrimp), mollusks (e.g., marine snails, octopuses) and other taxa. Because such organisms live in close proximity to the seafloor, they can be impacted by changes in sediments affected by both point and non-point sources (e.g., discharges from ocean outfalls and storm drains, surface runoff from watersheds, outflows from rivers and bays, disposal of dredge materials; see Chapter 4). For these reasons, their assessment has become an important focus of ocean monitoring programs throughout the world, but especially in the SCB where they have been sampled extensively for almost 40 years on the mainland shelf (Cross and Allen 1993).

Demersal fish and megabenthic invertebrate communities are inherently variable and are influenced by many factors. Therefore, distinguishing changes in these communities caused by anthropogenic influences such the SBOO wastewater discharge from other, more natural, sources is an important aspect of the ocean monitoring program. Natural factors that may affect these organisms include prey availability (Cross et al. 1985), bottom relief and sediment structure (Helvey and Smith 1985), and changes in water temperatures associated with large scale oceanographic events such as El Niño/ La Niña oscillations (Karinen et al. 1985). These factors can affect migration patterns of adult fish or the recruitment of juveniles into an area (Murawski 1993). Population fluctuations that affect species diversity and abundance of both fishes and invertebrates may also be due to the mobile nature of many species (e.g., fish schools, urchin aggregations).

This chapter presents analyses and interpretations of the trawl survey data collected during 2010, as well as a long-term assessment of these communities from 1995 through 2010. The primary goals are to: (1) identify possible effects of wastewater discharge on demersal fishes and megabenthic invertebrates, (2) determine the presence or absence of biological impacts near the discharge site, and (3) identify spatial or temporal trends in demersal community structure in the region.

Materials and Methods

Field Sampling

Trawl surveys were conducted at seven fixed monitoring stations around the SBOO during 2010 (Figure 6.1). These surveys were conducted during January (winter), April (spring), July (summer), and October (fall) for a total of 28 community trawls during the year. These stations, designated SD15–SD21, are located along the 28-m depth contour and encompass an area ranging from south of Point Loma, California (USA) to an area off Punta Bandera, Baja California (Mexico). A single trawl was performed at each station during each survey using a 7.6-m Marinovich otter trawl fitted

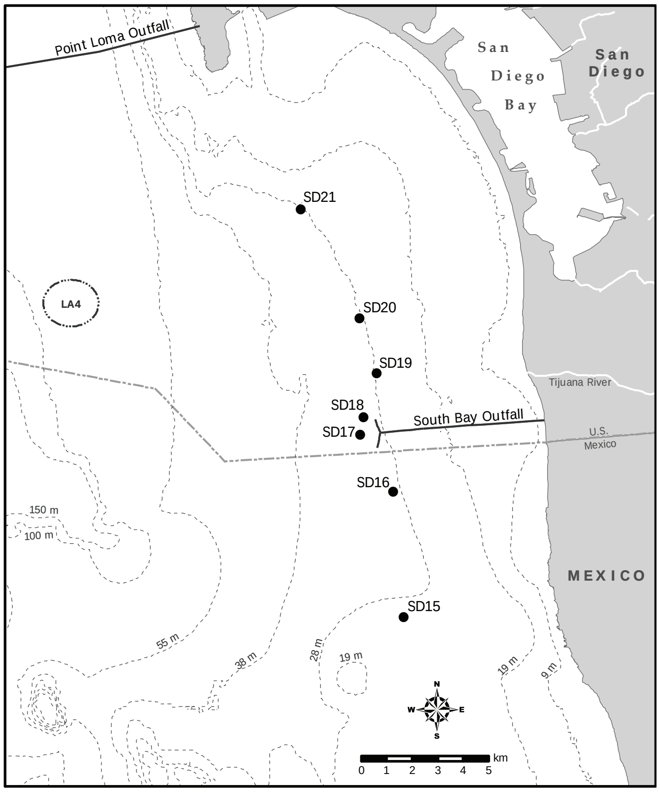


Figure 6.1
Otter trawl station locations, South Bay Ocean Outfall Monitoring Program.

with a 1.3-cm cod-end mesh net. The net was towed for 10 minutes bottom time at a speed of about 2.0 knots along a predetermined heading.

The total catch from each trawl was brought onboard ship for sorting and inspection. All fishes and invertebrates captured were identified to species or to the lowest taxon possible. If an animal could not be identified in the field, it was returned to the laboratory for further identification. For fishes, the total number of individuals and total biomass (kg, wet weight) were recorded for each species. Additionally, each individual fish was inspected for physical anomalies or indicators of disease (e.g., tumors, lesions, fin erosion, discoloration) as well as the presence of external parasites, and then measured to the nearest centimeter size class (standard lengths). For invertebrates, the total number of individuals was recorded per species. Due to the small size of most organisms, invertebrate biomass was typically measured as a composite weight of all taxa combined, though large or exceptionally abundant taxa were weighed separately.

Data Analyses

Populations of each fish and invertebrate species were summarized as percent abundance per haul, frequency of occurrence among stations, mean abundance per haul, and mean abundance per occurrence. In addition, species richness (number of taxa), total abundance, total biomass, and Shannon diversity index (H') were calculated for each station/survey. For historical comparisons, data were grouped as "nearfield" stations (SD17, SD18), "south farfield" stations (SD15, SD16), and "north farfield" stations (SD19, SD20, SD21). The two nearfield stations were those located closest to the outfall (i.e., within 1000 m of the outfall wye).

Multivariate analyses of demersal fish communities sampled in the region were performed using data collected from 1995 through 2010. In order to reduce statistical noise due to seasonal variation in population abundances, analyses were limited to data from the July surveys only. PRIMER software was used to examine spatio-temporal patterns in the overall similarity of fish assemblages in the region (Clarke 1993, Warwick 1993, Clarke and Gorley 2006). These analyses included classification by hierarchical agglomerative clustering with group-average linking and ordination by non-metric multidimensional scaling (nMDS). The fish abundance data were square-root transformed and the Bray-Curtis measure of similarity was used as the basis for classification. Because species composition was sparse at some stations, a "dummy" species with an abundance value of 1 was added to all samples prior to computing similarities (Clarke and Gorley 2006). Similarity profile (SIMPROF) analysis was used to confirm non-random structure of the dendrogram (Clarke et al. 2008). Similarity percentages (SIMPER) analysis was subsequently used to identify which species primarily account for observed differences between cluster groups, as well as to identify species typical of each group.

Table 6.1

Demersal fish species collected in 28 trawls in the SBOO region during 2010. PA = percent abundance; FO = frequency of occurrence; MAH = mean abundance per haul; MAO = mean abundance per occurrence.

Species	PA	FO	MAH	MAO	Species	PA	FO	MAH	MAO
Speckled sanddab	49	100	114	114	Basketweave cuskeel	<1	7	<1	3
California lizardfish	21	96	49	51	Fantail sole	<1	18	<1	1
Yellowchin sculpin	6	54	15	27	Vermilion rockfish	<1	14	<1	2
English sole	5	64	12	19	Pink seaperch	<1	7	<1	3
White croaker	4	39	10	25	Stripetail rockfish	<1	11	<1	2
Roughback sculpin	3	64	7	11	California skate	<1	11	<1	1
Pacific pompano	3	18	7	37	Kelp bass	<1	4	<1	4
California tonguefish	1	75	3	5	Pygmy poacher	<1	14	<1	1
Longfin sanddab	1	57	3	6	Spotted cuskeel	<1	11	<1	1
Hornyhead turbot	1	82	3	4	Spotted turbot	<1	11	<1	1
Longspine combfish	1	43	2	6	Diamond turbot	<1	7	<1	2
Queenfish	1	25	2	6	Sarcastic fringehead	<1	11	<1	1
Shiner perch	<1	29	1	3	Barcheek pipefish	<1	7	<1	1
Plainfin midshipman	<1	36	1	2	California butterfly ray	<1	4	<1	2
California scorpionfish	<1	29	1	2	Curlfin sole	<1	7	<1	1
Northern anchovy	<1	18	1	3	Pacific angel shark	<1	7	<1	1
Specklefin midshipman	<1	11	1	5	Bigmouth sole	<1	4	<1	1
California halibut	<1	25	<1	1	Brown rockfish	<1	4	<1	1
Ocean whitefish	<1	14	<1	2	Kelp perch	<1	56	<1	1
Round stingray	<1	14	<1	2	Kelp pipefish	<1	4	<1	1
Shovelnose guitarfish	<1	25	<1	1	Pacific electric ray	<1	4	<1	1
Thornback	<1	18	<1	2					

Results

Demersal Fish Community Parameters

Forty-three species of fish were collected from the monitoring stations surrounding the SBOO in 2010 (Table 6.1, Appendix E.1). The total catch for the year was 6570 individuals, representing an average of 235 fish per trawl. As in previous years, the speckled sanddab was the dominant species collected. This species occurred in every haul, accounted for 49% of all fishes collected, and averaged 114 individuals per haul. California lizardfish were also abundant, and accounted for 21% of the total number of fishes collected. This species occurred in 96% of hauls, and averaged 49 fish per haul. Together, Pacific sanddab and California lizardfish accounted for 70% of all fishes collected in 2010. Other species collected frequently (≥50% of the trawls) included yellowchin sculpin, English sole, roughback sculpin, hornyhead turbot, California tonguefish, and longfin sanddab. The majority of species sampled in the South Bay outfall region tended to be relatively small fish with an average length <25 cm (see Appendix E.1). Although larger fishes such as the Pacific angel shark, Pacific electric ray, shovelnose guitarfish, California halibut, California skate, round stingray, California butterfly ray, and thornback were also caught during the year, these species were relatively rare.

During 2010, species richness (number of taxa) and diversity (H') values were relatively low compared to values reported previously for other areas of the SCB (Allen et al. 1998, 2002, 2007), while abundance and biomass values varied widely (Table 6.2). No more than 18 species occurred in any one haul, and all corresponding H' values were less than 2.14. As in previous years, trawls from station SD15 located the farthest south in Mexican waters had the lowest species richness (mean = 8 species; Figure 6.2) and

Table 6.2

Summary of demersal fish community parameters for SBOO trawl stations sampled during 2010. Data are included for species richness (number of species), abundance (number of individuals), diversity (H'), and biomass (kg, wet weight); SD = standard deviation.

					Annual							Annual	
Station	**Jan**	**Apr**	**Jul**	**Oct**	**Mean**	**SD**	**Station**	**Jan**	**Apr**	**Jul**	**Oct**	**Mean**	**SD**
Species richness							*Abundance*						
SD15	9	9	8	6	8	1	SD15	127	121	435	293	244	150
SD16	12	10	11	13	12	1	SD16	159	148	425	441	293	162
SD17	7	12	8	10	9	2	SD17	62	95	392	379	232	178
SD18	15	15	8	7	11	4	SD18	143	286	432	217	270	123
SD19	12	13	10	12	12	1	SD19	158	79	453	158	212	165
SD20	15	13	9	8	11	3	SD20	86	123	312	199	180	100
SD21	18	14	14	11	14	2	SD21	127	61	311	348	212	140
Survey Mean	12	12	10	10			Survey Mean	123	130	394	291		
Survey SD	4	2	2	3			Survey SD	37	75	59	104		
Diversity							*Biomass*						
SD15	0.95	0.52	0.68	0.79	0.73	0.18	SD15	3.0	1.8	14.0	3.9	5.7	5.6
SD16	1.27	1.09	1.21	1.47	1.26	0.16	SD16	3.9	2.0	5.2	9.1	5.0	3.0
SD17	1.63	1.85	1.33	1.60	1.60	0.21	SD17	2.6	2.6	4.3	4.8	3.6	1.1
SD18	1.82	1.44	0.87	1.00	1.28	0.43	SD18	9.5	11.8	4.4	2.7	7.1	4.3
SD19	1.54	1.43	1.16	1.54	1.42	0.18	SD19	6.7	2.3	5.1	4.1	4.5	1.8
SD20	1.71	1.20	1.48	1.31	1.43	0.22	SD20	3.4	3.4	4.5	4.9	4.0	0.8
SD21	2.09	2.14	1.28	1.83	1.83	0.39	SD21	29.3	5.4	3.9	6.0	11.1	12.1
Survey Mean	1.57	1.38	1.15	1.36			Survey Mean	8.3	4.2	5.9	5.1		
Survey SD	0.37	0.53	0.28	0.36			Survey SD	9.5	3.6	3.6	2.0		

diversity (mean H' = 0.73) values. Total abundance ranged from 61 to 453 fishes per haul over all stations and quarters, which generally mirrored variation in abundances of speckled sanddabs, California lizardfish, white croaker, yellowchin sculpin, and English sole (Figure 6.3, Appendix E.2). Biomass varied from 1.8 to 29.3 kg per haul, with higher values coincident with greater numbers of fishes or the presence of large individual fish (Appendices E.2, E.3). For example, the highest biomass measured during the year was 29.3 kg at station SD21 in January, which included the catch of a single Pacific angel shark weighing 23 kg.

Although average species richness values at SBOO monitoring sites have remained within a narrow range over the years (i.e., 4–14 species/station/year), the average abundance per haul has varied considerably (i.e., 28–308 fish/station/year), mostly in response to population fluctuations of a few dominant species (Figures 6.2, 6.3). For example, average abundance at four of the seven stations decreased between 2009 and 2010 (stations SD17, SD19, SD20, SD21); these reductions followed drops in average speckled sanddab numbers at the same stations. In contrast, overall abundances increased at stations SD15, SD16 and SD18, reflecting greater numbers of yellowchin sculpin and California lizardfish. Whereas fluctuations of common species such as speckled sanddab, California lizardfish, roughback sculpin and yellowchin sculpin tend to occur across large portions of the study area (i.e., over multiple stations), intra-station variability is most often associated with large hauls of schooling species that occur less frequently. Examples of this include: (1) large hauls of white croaker that occurred primarily at station SD21 in 1996; (2) a large haul of northern anchovy that occurred in a single haul from station SD16 in 2001; (3) a large

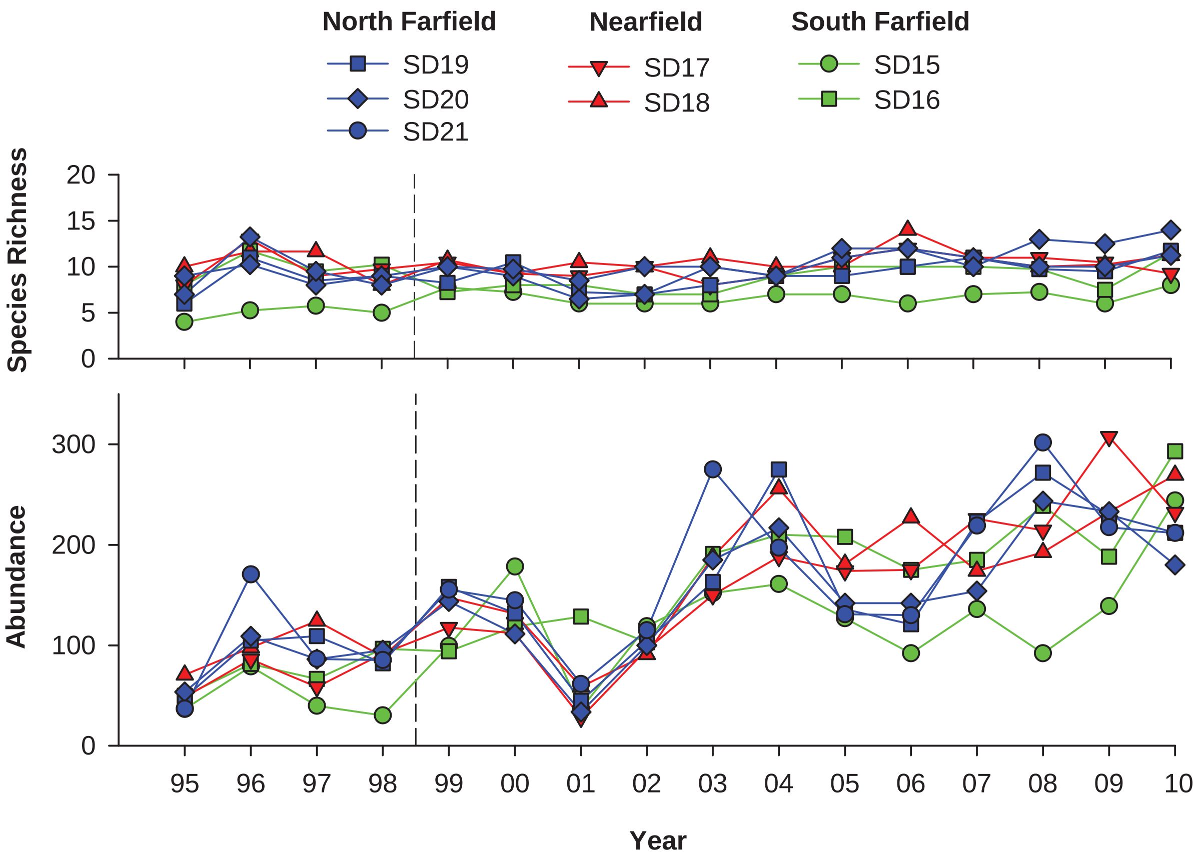


Figure 6.2
Species richness and abundance of demersal fish collected at each SBOO trawl station between 1995 and 2010. Data are annual means; $n=2$ in 1995 and $n=4$ between 1996–2010. Dashed line represents initiation of wastewater discharge.

haul of Pacific pompano that was captured in a single haul at station SD21 in 2008. Overall, none of the observed changes appear to be associated with wastewater discharge.

Classification of Demersal Fish Assemblages

Ordination and cluster analyses performed on data collected between 1995 and 2010 (July surveys only) discriminated between five main types of fish assemblages in the South Bay outfall region (Figure 6.4). These assemblages (cluster groups A–E) were distinguished by differences in the relative abundances of the common species present, although most were dominated by speckled sanddabs. The distribution of assemblages in 2010 was generally similar to that seen in previous years, especially between 2003–2009, and no patterns appear to be associated with proximity to the outfall. Instead, most differences appear more closely related to large-scale oceanographic events (e.g., El Niño in 1998) or the unique characteristics of a specific station location. For example, station SD15 located far south of the outfall off northern Baja California often grouped apart from the remaining stations. The composition and main characteristics of each cluster group are described below.

Cluster group A consisted of trawls from stations SD16 and SD17 sampled in July 2006 (Figure 6.4). This group was unique in that it averaged more than 200 California lizardfish per haul, more than an order of magnitude greater than in any other cluster group (Table 6.3). The second and third most abundant species composing this group were the speckled sanddab (~56 fish/haul) and yellowchin sculpin (~15 fish/haul). The relatively high numbers of California lizardfish and low numbers of speckled sanddabs helped distinguish these trawls from others included in cluster groups B, C, D (see Appendix E.4).

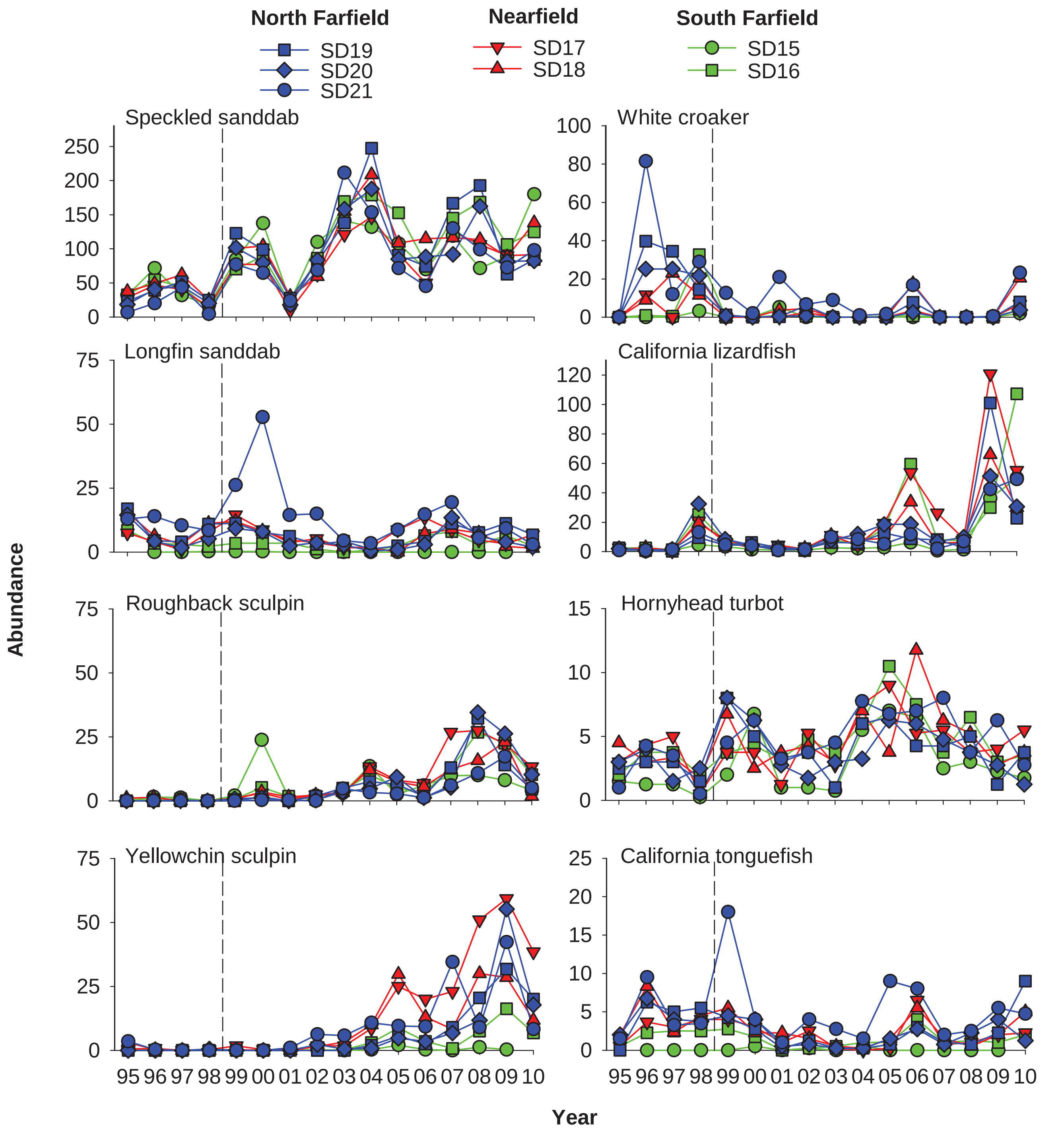


Figure 6.3
The eight most abundant fish species collected in the SBOO region between 1995 and 2010. Data are annual means per station; $n=2$ in 1995 and $n=4$ between 1996–2010. Dashed line represents initiation of wastewater discharge.

Cluster group B was the largest group, representing 45 trawls collected between 2003 and 2010 (Figure 6.4). Assemblages represented by this group had the highest number of speckled sanddabs (~157 fish/haul) and yellowchin sculpin (~33 fish/haul), and moderate numbers of California lizardfish (~34 fish/haul) (Table 6.3). In particular, the relatively high numbers of speckled sanddabs helped distinguish this cluster from the other groups (Appendix E.4), as did the relative abundance of yellowchin sculpin, California lizardfish, longfin sanddabs and roughback sculpin.

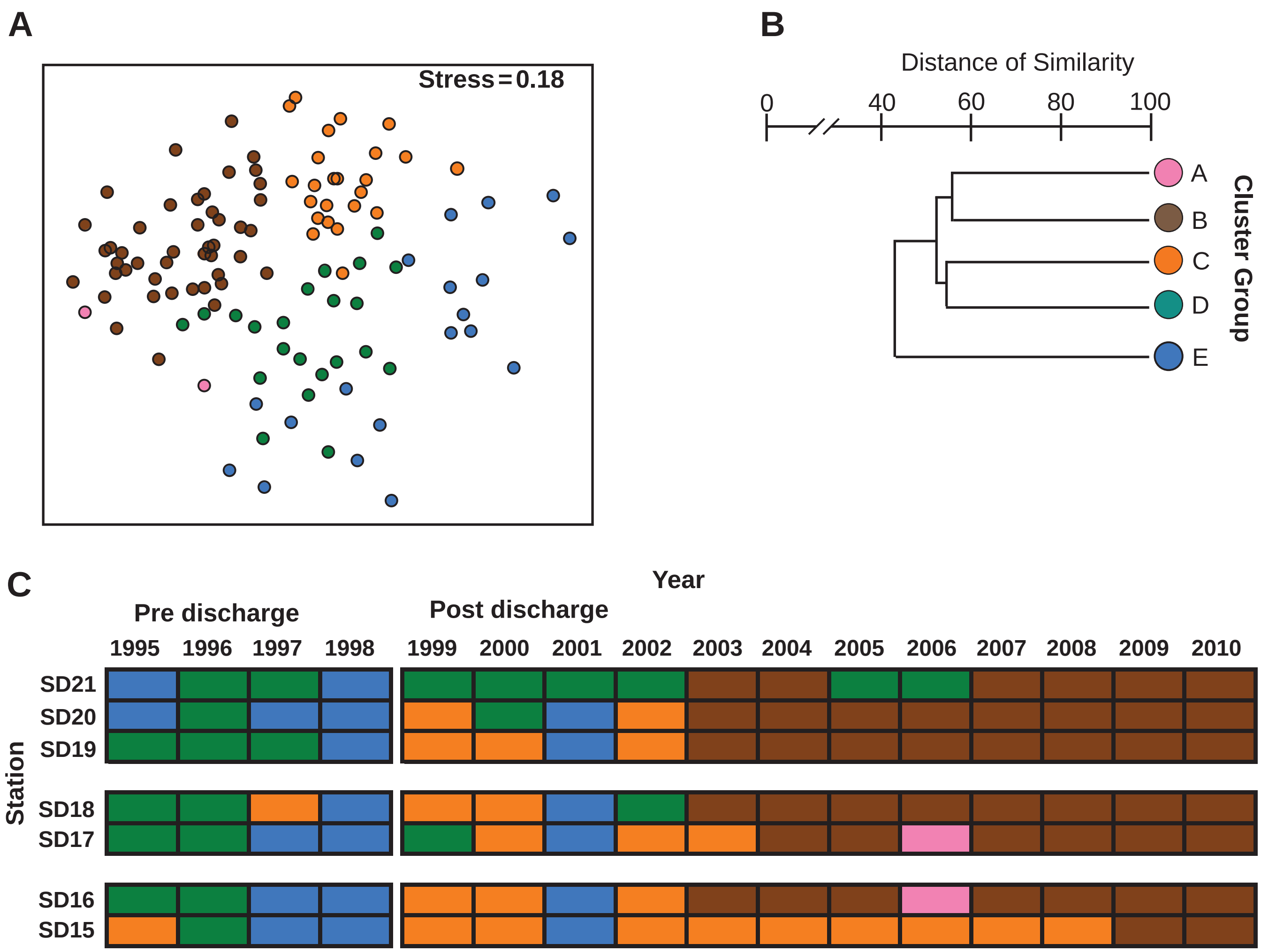


Figure 6.4

Results of multivariate analyses of demersal fish assemblages collected at SBOO trawl stations between 1995 and 2010 (July surveys only). Data are presented as (A) nMDS ordination, (B) a dendrogram of major cluster groups, and (C) a matrix showing distribution of cluster groups over time.

Cluster group C was the second largest group and comprised 24 trawls that occurred at a mix of sites sampled during all years except 1996, 1998, 2001, 2009 and 2010 (Figure 6.4). This mix of sites included station SD15 in 10 out of 16 surveys and a majority of the other stations sampled during 1999, 2000 and 2002. Group C was characterized by the second highest average abundance of speckled sanddabs (~105 fish/haul) and very few other species (Table 6.3). The lack of other relatively common species helped distinguish this group from the other cluster groups (Appendix E.4).

Cluster group D was the third largest group and comprised most stations sampled during 1995 and 1996, plus one or two stations during almost every survey conducted between 1997 and 2006. Seven of these latter hauls occurred at station SD21. In comparison to other cluster groups, assemblages represented by this cluster group were characterized by moderate numbers of speckled sanddabs (~62 fish/haul); as well as relatively high numbers of longfin sanddabs (~24 fish/haul) and hornyhead turbot (~6 fish/haul). The relative abundance of speckled and longfin sanddabs, California tonguefish, and English sole helped distinguish these trawls from those that occurred in other cluster groups (Appendix E.4).

Cluster group E comprised trawls from years associated with warmer water conditions, including 1995, 1997–1998, and 2001 (Figure 6.4). This group was characterized by the lowest overall

Table 6.3

Description of cluster groups A–E defined in Figure 6.4. Data include number of hauls, mean species richness, mean total abundance, and mean abundance of the five most abundant species for each station group. Bold values indicate species that were considered "characteristic" of that group according to SIMPER analysis (i.e., greatest percentage contribution to within-group similarity).

	Group A	Group B	Group C	Group D	Group E
Number of Hauls	2	45	24	22	19
Mean Species Richness	8	10	6	10	8
Mean Abundance	299	259	117	117	48
Species			**Mean Abundance**		
California lizardfish	212	34	3	3	11
Speckled sanddab	56	**157**	**105**	**62**	**18**
Yellowchin sculpin	15	33	<1	3	<1
Longfin sanddab	5	8	<1	24	5
Hornyhead turbot	4	4	3	6	3
Roughback sculpin	3	11	<1	1	—
California tonguefish	3	2	1	5	1
English sole	2	3	<1	3	2
California scorpionfish	1	1	1	1	1
Spotted turbot	—	1	2	1	2

abundance (48 fish/haul on average), with very low numbers of speckled sanddabs (18 fish/haul) and most other common species (Table 6.3). The overall low number of fish present in these trawls helped distinguish them from those that occurred in other cluster groups (Appendix E.4).

Physical Abnormalities and Parasitism

Demersal fish populations appeared healthy in the South Bay outfall region during 2010. There were no incidences of fin rot, discoloration, skin lesions, tumors, or other noticeable physical abnormalities or indicators of disease among fishes collected during the year. Evidence of parasitism was also low for trawl-caught fishes in the region. Only four external parasites were observed associated with their hosts. These included leeches (Annelida, Hirudinea) found attached to a single curlfin sole collected from station SD21 in April, two hornyhead turbots collected from SD17 and SD18 in July, and a speckled sanddab collected at station SD21 in October. In addition, the parasitic isopod *Elthusa vulgaris* was identified as part of the trawl catch throughout the year (see Appendix E.5). Since cymothoids often become detached from their hosts during retrieval and sorting of the trawl catch, it is unknown which fishes were actually parasitized by these isopods. However, *E. vulgaris* is known to be especially common on sanddabs and California lizardfish in southern California waters, where it may reach infestation rates of 3% and 80%, respectively (Brusca 1978, 1981).

Megabenthic Invertebrate Community Parameters

A total of 1924 megabenthic invertebrates (~69 per trawl), representing 68 taxa, were collected during 2010 (Table 6.4, Appendix E.5). The shrimp *Crangon nigromaculata* was the most abundant species; it accounted for 31% of the total invertebrate abundance and occurred in 68% of the trawls, at a rate of 32 shrimp per occurrence. The sea star *Astropecten verrilli* was the most frequently collected species, occurring in 86% of the hauls, but it accounted for only 14% of the total abundance. With the exception of *C. nigromaculata* and *A. verrilli*, all of the species collected averaged no more than six individuals per haul. The only other species that occurred frequently (≥50% of the trawls) was the crab *Metacarcinus gracilis*.

Table 6.4

Species of megabenthic invertebrates collected in 28 trawls in the SBOO region during 2010. PA=percent abundance; FO=frequency of occurrence; MAH=mean abundance per haul; MAO=mean abundance per occurrence.

Species	PA	FO	MAH	MAO	Species	PA	FO	MAH	MAO
Crangon nigromaculata	31	68	21	32	*Philine auriformis*	<1	11	<1	1
Astropecten verrilli	14	86	10	11	*Heptacarpus palpator*	<1	7	<1	2
Doryteuthis opalescens	8	7	6	82	*Podochela hemphillii*	<1	7	<1	2
Dendraster terminalis	6	25	4	18	*Pteropurpura festiva*	<1	7	<1	2
Portunus xantusii	4	25	3	12	*Scyra acutifrons*	<1	4	<1	3
Ophiura luetkenii	4	18	3	16	*Strongylocentrotus franciscanus*	<1	4	<1	3
Ophiothrix spiculata	4	32	3	9	*Aphrodita refulgida*	<1	7	<1	1
Octopus rubescens	3	36	2	5	*Forreria belcheri*	<1	7	<1	1
Dendronotus iris	3	29	2	6	*Glossaulax reclusianus*	<1	7	<1	1
Metacarcinus gracilis	2	50	1	3	Hirudinea	<1	7	<1	1
Sicyonia ingentis	2	4	1	39	*Megasurcula carpenteriana*	<1	7	<1	1
Pyromaia tuberculata	2	32	1	4	*Pleurobranchaea californica*	<1	7	<1	1
Heterocrypta occidentalis	2	29	1	4	*Aphrodita armifera*	<1	4	<1	2
Platymera gaudichaudii	1	46	1	2	*Acanthoptilum* sp	<1	4	<1	1
Elthusa vulgaris	1	43	1	2	*Alpheus clamator*	<1	4	<1	1
Farfantepenaeus californiensis	1	18	1	4	*Antiplanes catalinae*	<1	4	<1	1
Kelletia kelletii	1	46	1	1	*Caesia perpinguis*	<1	4	<1	1
Pisaster brevispinus	1	32	1	2	*Calliostoma canaliculatum*	<1	4	<1	1
Flabellina iodinea	1	32	1	2	*Crassispira semiinflata*	<1	4	<1	1
Crangon alba	1	14	1	4	*Lamellaria diegoensis*	<1	4	<1	1
Acanthodoris brunnea	1	25	<1	2	*Luidia armata*	<1	4	<1	1
Randallia ornata	1	29	<1	1	*Luidia foliolata*	<1	4	<1	1
Lytechinus pictus	1	21	<1	2	*Megastraea turbanica*	<1	4	<1	1
Heptacarpus stimpsoni	1	14	<1	3	*Ophiopteris papillosa*	<1	4	<1	1
Pandalus danae	1	11	<1	4	*Orthopagurus minimus*	<1	4	<1	1
Sicyonia penicillata	<1	21	<1	1	*Paguristes ulreyi*	<1	4	<1	1
Cancridae	<1	14	<1	2	*Panulirus interruptus*	<1	4	<1	1
Pagurus spilocarpus	<1	18	<1	1	*Paraxanthias taylori*	<1	4	<1	1
Crossata californica	<1	14	<1	1	*Pinnixa franciscana*	<1	4	<1	1
Acanthodoris rhodoceras	<1	7	<1	3	*Romaleon antennarius*	<1	4	<1	1
Hemisquilla californiensis	<1	14	<1	1	*Sicyonia disedwardsi*	<1	4	<1	1
Metacarcinus anthonyi	<1	14	<1	1	*Spirontocaris prionota*	<1	4	<1	1
Paguristes bakeri	<1	7	<1	2	*Triopha maculata*	<1	4	<1	1
Loxorhynchus grandis	<1	11	<1	1	*Tritonia diomedea*	<1	4	<1	1

Megabenthic invertebrate community structure varied among stations and between surveys during the year (Table 6.5). Species richness ranged from 5 to 19 species per haul, diversity (H') values ranged from 0.7 to 2.5 per haul, and total abundance ranged from 11 to 215 individuals per haul. The biggest hauls were characterized by large numbers of various species collected at multiple stations during each survey (Appendix E.6). For example, the shrimp *C. nigromaculata*, the crab *Portunus xantusii*, and the brittle star *Ophiothrix spiculata* dominated the hauls taken at stations SD18 and SD21 in January, whereas the squid *D. opalescens*, the sea star *A. verrilli*, the brittle star *Ophiura luetkenii*, and the sand dollar *Dendraster terminalis* dominated hauls from stations SD15 and SD17 in October. Biomass varied from 0.1 to 7.0 kg per haul, with higher biomass values reflecting large abundances

Table 6.5

Summary of megabenthic invertebrate community parameters for SBOO trawl stations sampled during 2010. Data are included for species richness (number of species), abundance (number of individuals), diversity (H'), and biomass (kg, wet weight); SD = standard deviation.

Station	Jan	Apr	Jul	Oct	Annual Mean	Annual SD	Station	Jan	Apr	Jul	Oct	Annual Mean	Annual SD
Species richness							*Abundance*						
SD15	9	7	6	7	7	1	SD15	75	42	90	121	82	33
SD16	11	12	12	11	12	1	SD16	83	100	77	45	76	23
SD17	9	6	16	8	10	4	SD17	87	26	44	215	93	85
SD18	18	9	19	16	16	5	SD18	157	72	58	73	90	45
SD19	12	5	10	8	9	3	SD19	39	20	26	19	26	9
SD20	10	8	7	8	8	1	SD20	51	11	43	17	31	19
SD21	17	13	10	11	13	3	SD21	212	55	19	47	83	87
Survey Mean	12	9	11	10			Survey Mean	101	47	51	77		
Survey SD	4	3	5	3			Survey SD	62	32	26	71		
Diversity							*Biomass*						
SD15	1.6	1.3	0.8	1.0	1.2	0.3	SD15	0.5	0.1	0.5	0.7	0.4	0.3
SD16	1.8	1.4	1.6	1.6	1.6	0.2	SD16	1.5	1.1	0.4	1.2	1.0	0.5
SD17	0.8	1.3	2.2	0.9	1.3	0.6	SD17	0.8	1.6	1.2	5.6	2.3	2.2
SD18	1.3	0.7	2.5	2.0	1.6	0.8	SD18	7.0	0.7	0.9	1.9	2.6	3.0
SD19	1.8	1.0	2.0	1.9	1.7	0.5	SD19	1.5	1.2	1.0	1.4	1.3	0.2
SD20	1.3	1.9	1.4	1.8	1.6	0.3	SD20	0.6	0.9	0.5	1.9	1.0	0.6
SD21	1.2	1.6	1.8	1.6	1.6	0.2	SD21	2.2	3.7	0.1	3.8	2.4	1.7
Survey Mean	1.4	1.3	1.8	1.6			Survey Mean	2.0	1.3	0.7	2.4		
Survey SD	0.4	0.4	0.6	0.4			Survey SD	2.3	1.1	0.4	1.7		

such as those described above, or the collection of relatively big animals such as large sea stars or crabs (Appendix E.6).

Variations in megabenthic invertebrate community structure in the South Bay outfall region generally reflect changes in species abundance (Figures 6.5, 6.6). Although species richness has varied little over the years (e.g., 4–16 species/trawl), annual abundance values have averaged between 7 and 548 individuals per haul. These large differences typically have been due to fluctuations in populations of several dominant species, including the sea urchin *Lytechinus pictus*, as well as *D. terminalis* and *C. nigromaculata* as previously mentioned. For example, station SD15 has had the highest average abundance for 9 of the last 15 years due to relatively large hauls of *A. verrilli* and *D. terminalis*. In addition, the high abundances recorded at station SD17 in 1996 were due to large hauls of *L. pictus*. None of the observed variability in the trawl-caught invertebrate communities appears to be related to the South Bay outfall.

Discussion

As in previous years, speckled sanddabs continued to dominate fish assemblages surrounding the SBOO during 2010. This species occurred at all stations and accounted for 49% of the total catch. Other characteristic, but less abundant species included the California lizardfish, yellowchin sculpin, English sole, roughback sculpin, hornyhead turbot, California tonguefish and longfin sanddab. Most of these common fishes were relatively small, averaging less than 25 cm in length. Although the composition and structure of the fish assemblages varied among stations, these differences were mostly due to variations in speckled sanddab,

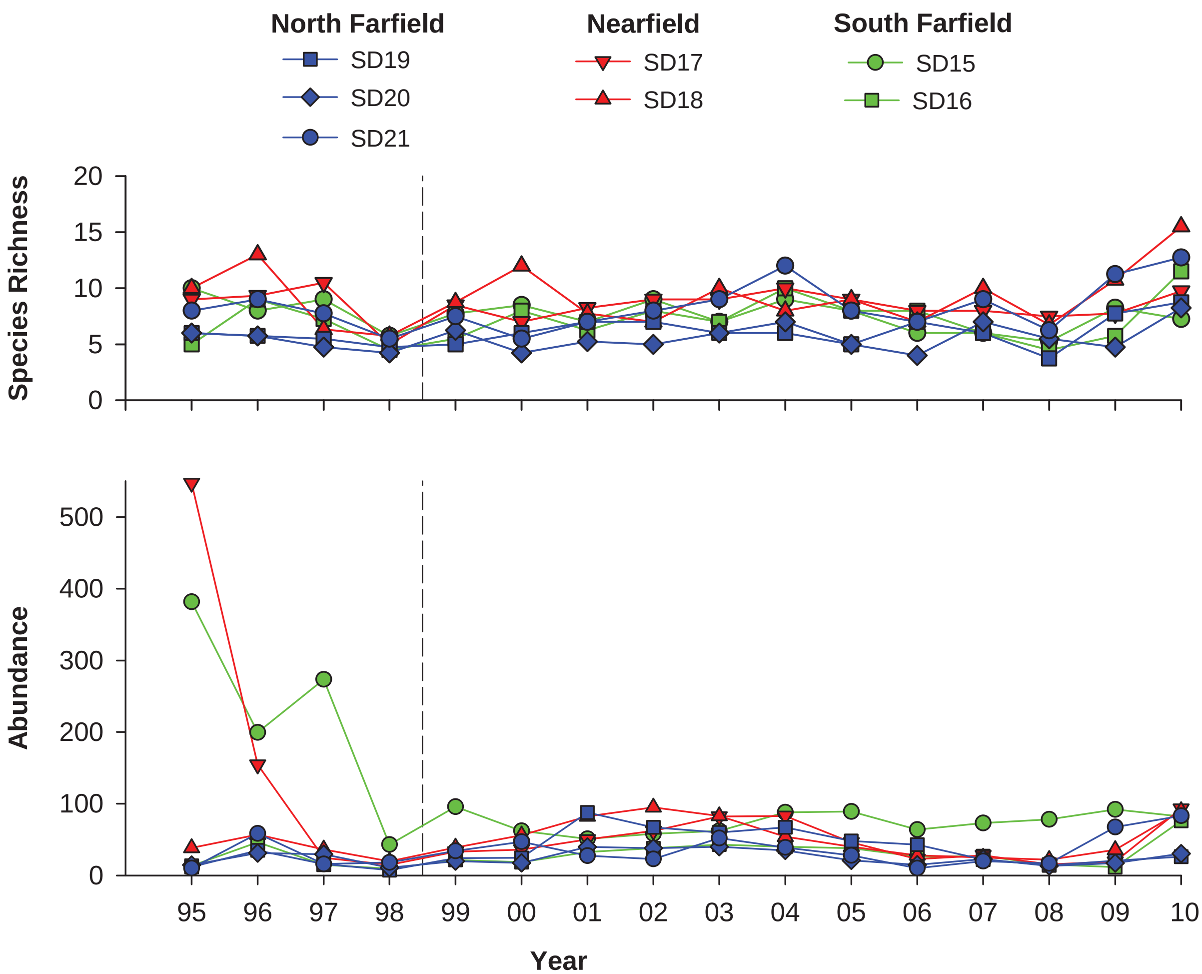


Figure 6.5
Species richness (number of species) and abundance (number of individuals) of megabenthic invertebrates collected at each trawl station between 1995 and 2010. Data are annual means; $n = 2$ in 1995 and $n = 4$ between 1996–2010. Dashed line represents initiation of wastewater discharge.

California lizardfish, white croaker, yellowchin sculpin and English sole populations.

During 2010, assemblages of megabenthic invertebrates in the region were dominated by the shrimp *Crangon nigromaculata* and the sea star *Astropecten verrilli*. Variations in community structure of the trawl-caught invertebrates generally reflect changes in the abundance of these two species, as well as other common species such the sand dollar *Dendraster terminalis*, the crab *Portunus xantusii*, the brittle stars *Ophiothrix spiculata* and *Ophiura luetkeni*, the shrimp *Sicyonia ingentis*, and the squid *Doryteuthis opalescence*.

Overall, results of the 2010 trawl surveys provide no evidence that wastewater discharged through the SBOO has affected either demersal fish or megabenthic invertebrate communities in the region. Although highly variable, patterns in the abundance and distribution of species were similar at stations located near the outfall and farther away, with no discernible changes in the region following the onset of wastewater discharge through the SBOO in January 1999. Instead, the high degree of variability observed during 2010 was similar to that observed in previous years (City of San Diego 2006–2010), including the period before initiation of wastewater discharge (City of San Diego 2000). In addition, the low species richness and abundances of fish and invertebrates found during the 2010 surveys are consistent with what is expected for the relatively shallow, sandy habitats in which the SBOO stations are located (Allen 1982, Allen et al. 1998, 2002,

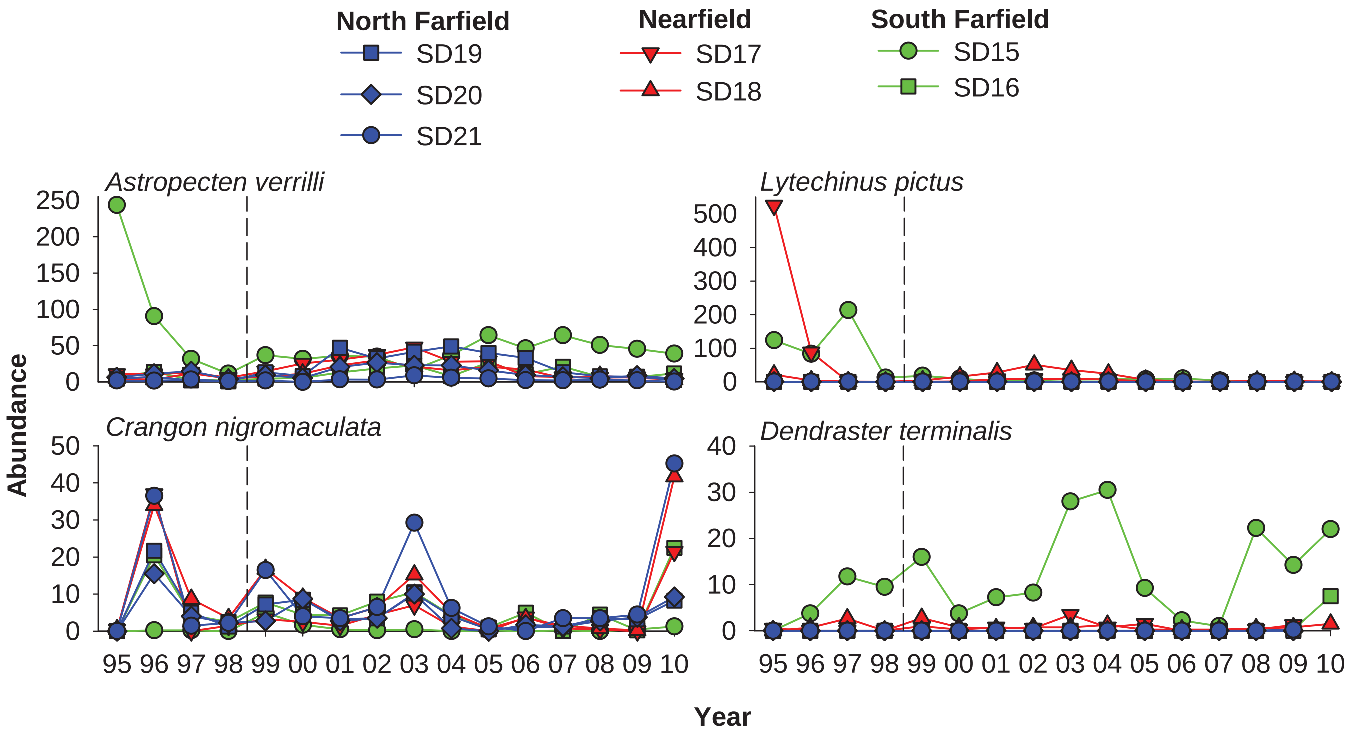


Figure 6.6
The four most abundant megabenthic invertebrate species collected in the SBOO region from 1995 through 2010. Data are annual means; $n=2$ in 1995 and $n=4$ between 1996–2010. Dashed line represents initiation of wastewater discharge.

2007). Changes in these communities appear to be more likely due to natural factors such as changes in ocean water temperatures associated with large-scale oceanographic events (e.g., El Niño or La Niña) or to the mobile nature of many of the resident species collected. Finally, the absence of disease or other physical abnormalities in local fishes suggests that populations in the area continue to be healthy.

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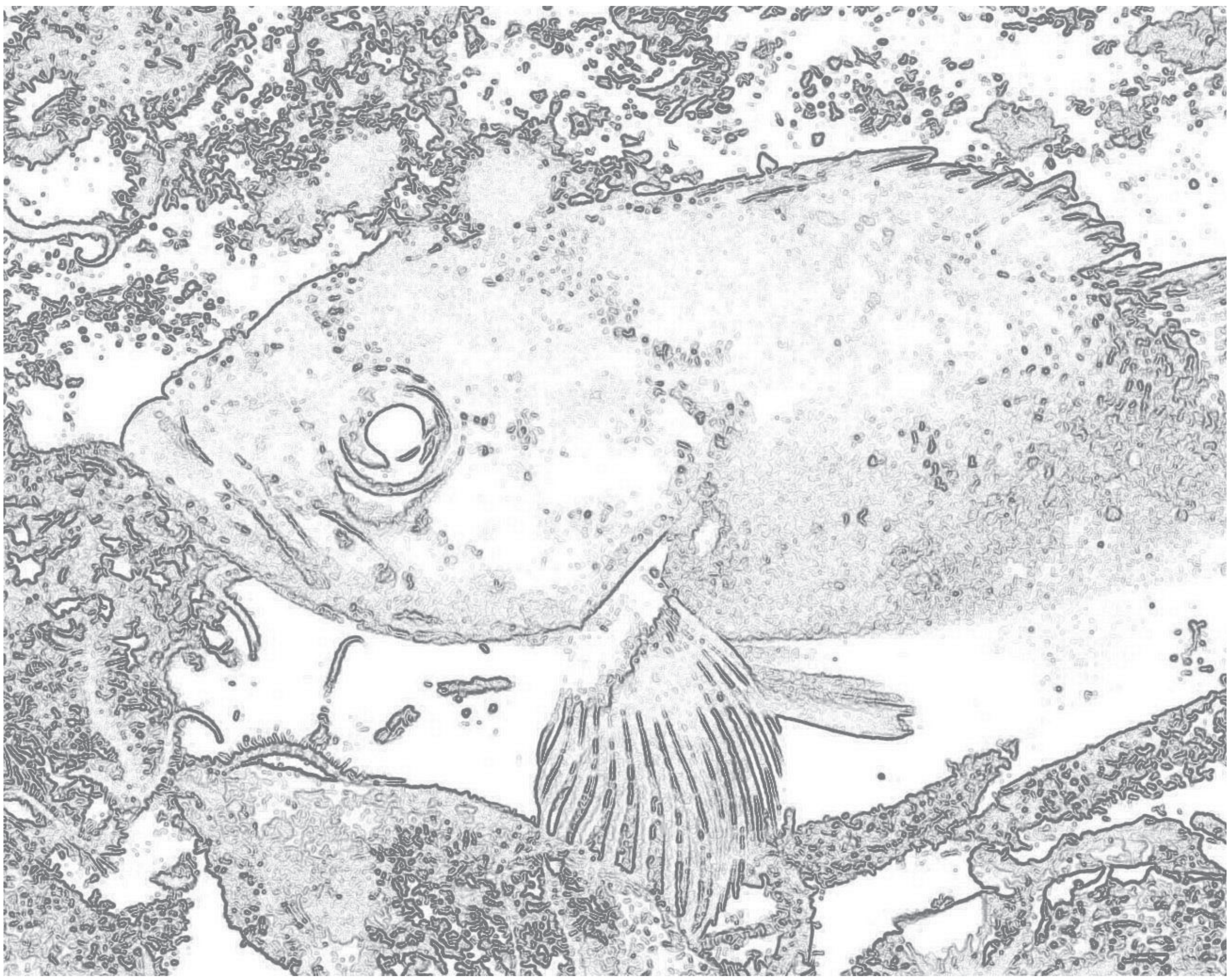
Chapter 7
Bioaccumulation of Contaminants in Fish Tissues



Chapter 7. Bioaccumulation of Contaminants in Fish Tissues

INTRODUCTION

Bottom dwelling (i.e., demersal) fishes are collected as part of the South Bay Ocean Outfall (SBOO) monitoring program to assess the accumulation of contaminants in their tissues. Anthropogenic inputs to the marine ecosystem (including municipal wastewater outfalls) can lead to increased concentrations of chemical contaminants within the local environment, and subsequently in the tissues of fishes and their prey. This is because the accumulation of contaminants in most fishes occurs through the biological uptake and retention of chemicals derived via various exposure pathways like the uptake of dissolved chemicals in seawater and the ingestion and assimilation of pollutants contained in different food sources (Rand 1995, USEPA 2000). In addition, demersal fishes may accumulate contaminants through ingestion of suspended particulates or sediments that contain pollutants because of their proximity to seafloor sediments. For this reason, the levels of many contaminants in the tissues of demersal fish are often related to those found in the environment (Schiff and Allen 1997), thus making these types of assessments useful in biomonitoring programs.

The bioaccumulation portion of the South Bay monitoring program consists of two components: (1) liver tissues are analyzed for trawl-caught fishes; (2) muscle tissues are analyzed for fishes collected by hook and line (rig fishing). Species of fish collected by trawling activities (see Chapter 6) are representative of the general demersal fish community, and certain species are targeted based on their prevalence in the community and therefore ecological significance. The chemical analysis of liver tissues in these fish is especially important for assessing population effects because this is the organ where contaminants typically concentrate (i.e., bioaccumulate). In contrast, fishes targeted for capture by rig fishing represent species that are characteristic of a typical sport fisher's catch, and are therefore considered of recreational and commercial importance and more directly relevant to human health concerns. Consequently, muscle tissue is analyzed from these fishes because it is the tissue most often consumed by humans, and therefore the results may have public health implications. All liver and muscle samples collected during the year are analyzed for contaminants as specified in the NPDES discharge permits that govern the SBOO monitoring program (see Chapter 1). Most of these contaminants are also sampled for the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program. NOAA initiated this program to detect and monitor changes in the environmental quality of the nation's estuarine and coastal waters by tracking contaminants thought to be of environmental concern (Lauenstein and Cantillo 1993).

This chapter presents the results of all tissue analyses that were performed on fishes collected in the SBOO region during 2010. The goals of the chapter are to: (1) assess the level of contaminant loading in the fishes of the SBOO region, (2) identify possible effects of wastewater discharge on contaminants in fishes collected near the discharge site, and (3) identify any spatial or temporal trends in contaminant loading.

Materials and Methods

Field Collection

Fishes were collected during April and October of 2010 at seven trawl and two rig fishing stations (Figure 7.1). California scorpionfish (*Scorpaena guttata*), English sole (*Parophrys vetulus*), hornyhead turbot (*Pleuronichthys verticalis*), and longfin sanddab (*Citharichthys xanthostigma*) were collected for analysis of liver tissues from the trawling stations, while California scorpionfish, brown rockfish (*Sebastes auriculatus*), copper rockfish (*Sebastes caurinus*), and vermilion rockfish (*Sebastes miniatus*) were collected for

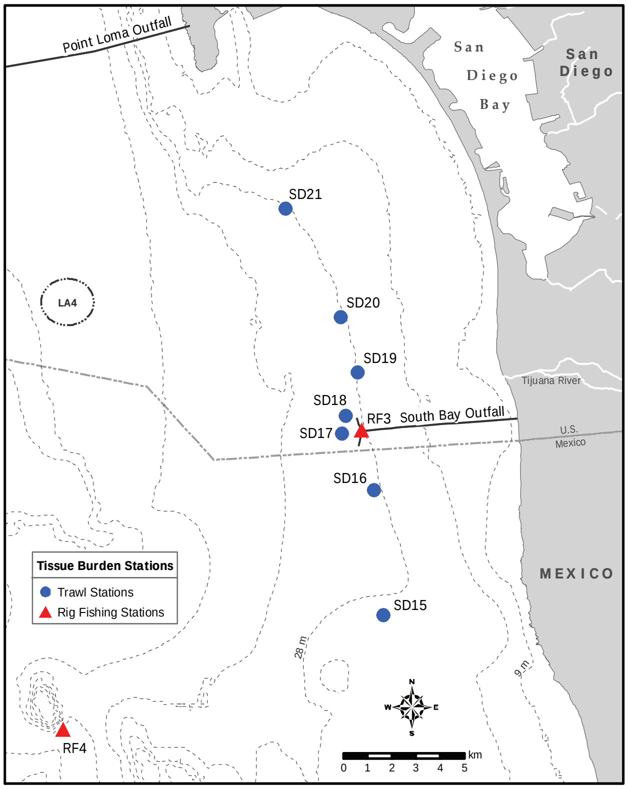


Figure 7.1
Otter trawl and rig fishing stations for the South Bay Ocean Outfall Monitoring Program.

analysis of muscle tissues at the two rig fishing stations (Table 7.1). All trawl-caught fishes were collected following City of San Diego guidelines (see Chapter 6 for a description of collection methods). Efforts to collect the targeted fish species at the trawl stations were limited to five 10-minute (bottom time) trawls per site. Fishes collected at the two rig fishing stations were caught within 1 km of the station location using standard rod and reel procedures; fishing effort was limited to 5 hours at each of these stations. Occasionally, insufficient numbers of the target species were obtained despite this effort, thus resulting in reduced number of composite samples at a particular station.

In order to facilitate the collection of sufficient tissue for subsequent chemical analysis, only fish ≥13 cm in standard length were retained. These fish were sorted into three composite samples per station, with each composite containing a minimum of three individuals. Composite samples were typically made up of a single species; the only exceptions were samples that consisted of mixed species of rockfish as indicated in Table 7.1. All fish collected were wrapped in aluminum foil, labeled, sealed in re-sealable plastic bags, placed on dry ice, and then transported to the City's Marine Biology Laboratory where they were held in the freezer at -80°C until dissection and tissue processing.

Tissue Processing and Chemical Analyses

All dissections were performed according to standard techniques for tissue analysis. A brief summary follows, but see City of San Diego (2004) for additional details. Prior to dissection, each fish was partially defrosted and then cleaned with a paper towel to remove loose scales and excess mucus. The standard length (cm) and weight (g) of each fish were recorded (Appendix F.1). Dissections were carried out on Teflon® pads that were cleaned between samples. The tissues (liver or muscle) from each dissected fish were then placed in separate glass jars for each composite sample, sealed, labeled, and stored in a freezer at -20°C prior to chemical analyses. All samples were subsequently delivered to the City's Wastewater Chemistry Services Laboratory for analysis within 10 days of dissection.

Chemical constituents were measured on a wet weight basis, and included trace metals, DDT and other chlorinated pesticides, polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs) (see Appendix F.2 for full listing and chemical abbreviations). Metals were measured in units of milligrams/kilogram tissue and are expressed herein as parts per million (ppm), while pesticides, PCBs, and PAHs were measured as micrograms/kilogram tissue and expressed as parts per billion (ppb). The data for each parameter reported herein were generally limited to values above method detection limits (MDL). However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified

Table 7.1
Species of fish collected from each SBOO trawl and rig fishing station during April and October 2010.

Survey	Station	Composite 1	Composite 2	Composite 3
April 2010	RF3	Brown rockfish	Brown rockfish	Mixed rockfish[a]
	RF4	California scorpionfish	California scorpionfish	California scorpionfish
	SD15	No sample[b]	No sample[b]	No sample[b]
	SD16	English sole	No sample[b]	No sample[b]
	SD17	English sole	Longfin sanddab	Hornyhead turbot
	SD18	English sole	English sole	Hornyhead turbot
	SD19	Longfin sanddab	English sole	Hornyhead turbot
	SD20	Hornyhead turbot	Hornyhead turbot	English sole
	SD21	Hornyhead turbot	Hornyhead turbot	English sole
October 2010	RF3	Brown rockfish	Brown rockfish	Brown rockfish
	RF4	California scorpionfish	California scorpionfish	California scorpionfish
	SD15	Hornyhead turbot	English sole	California scorpionfish
	SD16	Longfin sanddab	English sole	Longfin sanddab
	SD17	Longfin sanddab	Longfin sanddab	Hornyhead turbot
	SD18	Longfin sanddab	Longfin sanddab	Longfin sanddab
	SD19	Longfin sanddab	Longfin sanddab	Longfin sanddab
	SD20	Longfin sanddab	Longfin sanddab	No sample[b]
	SD21	Longfin sanddab	Longfin sanddab	Hornyhead turbot

[a] Includes vermilion and copper rockfish; [b] Insufficient fish collected (see text)

by mass-spectrometry (i.e., spectral peaks confirmed). A more detailed description of the analytical protocols is provided by the Wastewater Chemistry Services Laboratory (City of San Diego 2011).

Data Analyses

Data summaries for each contaminant include detection rates (i.e., number of reported values/ number of samples), minimum, maximum, and mean detected values of each parameter by species. Totals for DDT, PCBs, and PAHs were calculated for each sample as the sum of the detected constituents. For example, total DDT (tDDT) equals the sum of all DDT derivatives while total PCB (tPCB) equals the sum of all congeners. The detected values for each of these individual constituents are listed in Appendix F.3. In addition, the distribution of frequently detected contaminants in fishes collected in the SBOO region was assessed by comparing concentrations in fishes collected at "nearfield" stations located within 1000 m of the SBOO (SD17, SD18, RF3) to those from "farfield" stations located farther away to the south (SD15, SD16), north (SD19–SD21), and west (RF4). Concentrations were also compared to values detected during the pre-discharge period when available. Because concentrations of contaminants can vary so much among different species of fish, only intra-species comparisons were used for these evaluations.

Finally, in order to address seafood safety and public health issues, the concentrations of contaminants found in fish muscle tissue samples collected in 2010 were compared to state, national, and international limits and standards. These include: (1) the California Office of Environmental Health Hazard Assessment (OEHHA), which has developed fish contaminant goals for chlordane, DDT, methylmercury, selenium, and PCBs (Klasing and Brodberg 2008); (2) the United States Food and Drug Administration (USFDA), which has set limits on the amount of mercury, total DDT, and chlordane in seafood that is to be sold for human consumption (Mearns et al. 1991); and (3) international standards for acceptable concentrations of various metals and DDT (Mearns et al. 1991).

Results

Contaminants in Trawl-Caught Fishes

Metals

Eleven metals occurred in ≥70% of the liver samples analyzed from trawl-caught fishes in the SBOO region during 2010, including aluminum, arsenic, cadmium, chromium, copper, iron, manganese, mercury, selenium, silver, and zinc (Table 7.2). Another seven metals (i.e., antimony, barium, beryllium, lead, nickel, thallium, tin) were also detected, but less frequently at rates between 3–65%. During 2010, several metals were found at levels that exceeded pre-discharge values (Figure 7.2). These included aluminum, arsenic, cadmium and mercury, which exceeded pre-discharge values in 28–47% of the samples, and copper, iron, manganese, selenium and zinc, which exceeded pre-discharge values in ≤11% of the samples. Most of these exceedances occurred in English sole and hornyhead turbot samples, and despite being higher than pre-discharge values, had low concentrations overall (e.g., <40 ppm over all species for 15 of the 18 metals).

Several metals occurred in concentrations that varied greatly among the different species of fish (Table 7.2). For example, the highest values of antimony, cadmium, copper, lead, mercury, nickel, selenium, silver, and thallium occurred in samples of longfin sanddab. In contrast, the highest concentrations of aluminum, barium, beryllium, chromium, manganese and zinc occurred in samples of hornyhead turbot, while the highest concentrations of arsenic, iron and tin were detected in samples of English sole. The only liver sample collected from a California scorpionfish during 2010 generally contained low concentrations of metals.

Intra-species comparisons between nearfield and farfield stations suggest that there was no clear relationship between contaminant loads in fish liver tissues and proximity to the outfall (Figure 7.2). In most cases, relatively high concentrations occurred throughout the region and showed no pattern relative to the outfall. However, the maximum values of arsenic, cadmium, and selenium in longfin sanddab liver tissues all occurred in a sample collected from outfall station SD17.

Pesticides

Two chlorinated pesticides were detected in fish liver tissues during 2010 (Table 7.3). DDT was found in every tissue sample with tDDT concentrations ranging from 9 to 300 ppb. The most frequently detected DDT derivative was p,p-DDE, which was found in 100% of these samples at concentrations up to 270 ppb (Appendix F.3). Additional DDT derivatives detected in more than 50% of the samples included o,p-DDE, p,p-DDD, and p,p-DDMU. The other pesticide detected in fish tissues during the past year, hexachlorobenzene (HCB), occurred in 64% of the samples at concentrations up to 5.9 ppb.

All DDT concentrations were below the maximum levels detected in the same species prior to wastewater discharge (Figure 7.3). HCB was not detected frequently during the pre-discharge period because of substantially higher detection limits. Overall, there were no clear relationships between concentrations of either DDT or HCB in fish tissues and proximity to the outfall (Figure 7.3).

PAHs and PCBs

PAHs were detected in a single longfin sanddab liver sample during 2010, at a concentration of 41.9 ppb (Table 7.3). In contrast, PCBs occurred in every tissue sample. PCB 138 and PCB 153/168 were the most frequently detected congeners in liver tissues as they were found in every sample; other frequently detected congeners (i.e., >50%) included PCB 66, PCB 70, PCB 74, PCB 99, PCB 101, PCB 118, PCB 149, PCB 180, PCB 183, PCB 187, and PCB 194 (Appendix F.3). Total PCB concentrations were highly variable in South Bay fish tissues, ranging from 4.4 to 465.9 ppb (Table 7.3). These concentrations were less than pre-discharge values, with no clear relationship with proximity to the outfall (Figure 7.3).

Table 7.2

Summary of metals in liver tissues of fishes collected at SBOO trawl stations during 2010. Data include the number of detected values (*n*), minimum, maximum and mean* detected concentrations per species, and the detection rate and max value for all species. Concentrations are expressed as parts per million (ppm); the number of samples per species is indicated in parentheses. See Appendix F.2 for MDLs and names for each metal represented by periodic table symbol.

	Al	**Sb**	**As**	**Ba**	**Be**	**Cd**	**Cr**	**Cu**	**Fe**	**Pb**	**Mn**	**Hg**	**Ni**	**Se**	**Ag**	**Ti**	**Sn**	**Zn**
California scorpionfish																		
n (out of 1)	1	0	1	1	0	1	1	1	1	0	1	1	0	1	1	0	0	1
Min	7.2	nd	0.7	0.033	nd	0.99	0.114	6.8	36.1	nd	0.54	0.070	nd	0.80	0.111	nd	nd	50.7
Max	7.2	nd	0.7	0.033	nd	0.99	0.114	6.8	36.1	nd	0.54	0.070	nd	0.80	0.111	nd	n	50.7
Mean	7.2	—	0.7	0.033	—	0.99	0.114	6.8	36.1	—	0.54	0.070	—	0.80	0.111	—	—	50.7
English sole																		
n (out of 9)	8	0	9	0	0	9	7	9	9	7	9	9	0	9	9	2	5	9
Min	nd	nd	2.5	nd	nd	0.63	nd	3.5	72.7	nd	0.76	0.020	nd	1.05	0.103	nd	nd	23.6
Max	7.4	nd	35.6	nd	nd	2.38	0.192	9.3	319.0	3.110	1.74	0.134	nd	3.07	0.447	0.573	0.567	79.4
Mean	5.8	—	16.6	—	—	1.57	0.143	6.9	192.4	1.206	1.40	0.090	—	2.08	0.207	0.532	0.342	40.4
Hornyhead turbot																		
n (out of 10)	8	0	10	3	1	10	8	10	10	0	10	10	0	10	10	3	6	10
Min	nd	nd	2.5	nd	nd	4.40	nd	5.5	34.1	nd	0.97	0.068	nd	0.58	0.140	nd	nd	34.7
Max	163.0	nd	5.9	0.169	0.009	8.37	0.237	11.0	69.8	nd	2.74	0.177	nd	1.59	0.268	0.632	0.286	88.5
Mean	47.3	—	4.1	0.126	0.009	6.56	0.156	8.0	52.4	—	1.74	0.128	—	1.08	0.210	0.558	0.240	49.6
Longfin sanddab																		
n (out of 16)	15	8	16	6	0	16	11	16	16	2	16	16	6	16	16	13	11	16
Min	nd	nd	3.8	nd	nd	1.48	nd	5.7	49.8	nd	0.90	0.051	nd	0.76	0.077	nd	nd	20.8
Max	9.7	0.433	18.7	0.074	nd	8.99	0.160	13.8	250.0	0.376	1.82	0.279	0.256	3.23	0.481	0.870	0.440	35.9
Mean	7.1	0.304	6.9	0.047	—	3.33	0.141	8.1	94.5	0.366	1.18	0.103	0.224	1.25	0.247	0.602	0.319	26.4
All Species:																		
Detection Rate (%)	89	22	100	28	3	100	75	100	100	25	100	100	17	100	100	50	61	100
Max Value	163.0	0.433	35.6	0.169	0.009	8.99	0.237	13.8	319.0	3.110	2.74	0.279	0.256	3.23	0.481	0.870	0.567	88.5

* Minimum and maximum values were calculated based on all samples, whereas means were calculated on detected values only.

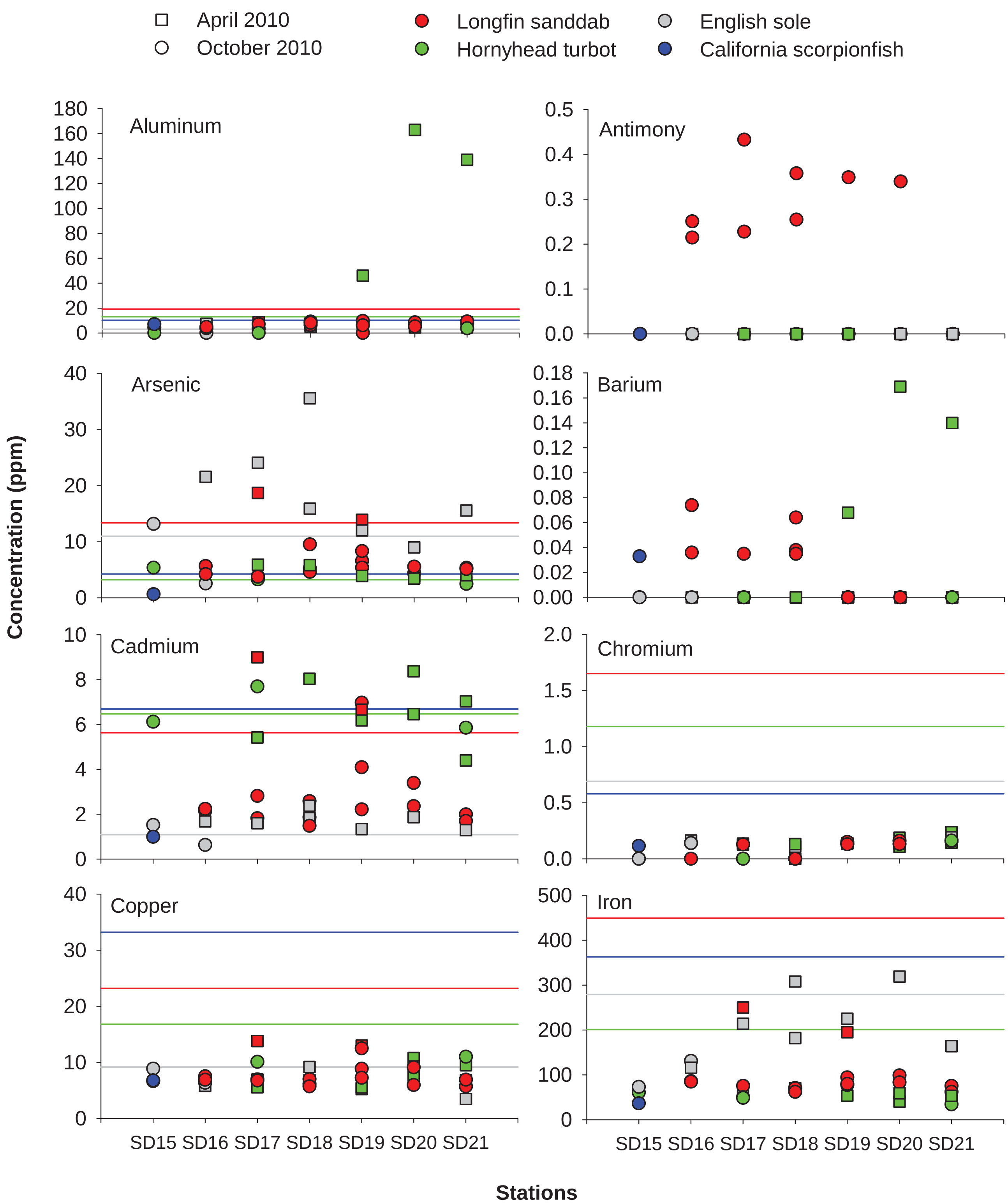


Figure 7.2

Concentrations of metals detected in more than 20% of liver tissues of fishes collected from each SBOO trawl station during 2010. Reference lines are maximum values detected during the pre-discharge period (1995–1998) for each species; missing lines indicate metals were not detected in that species pre-discharge because of substantially higher detection limits. To differentiate between missing values (i.e., samples that were not collected or not analyzed; see Table 7.1) and non-detects, zeros were added as placeholders for non-detected values. Stations SD17 and SD18 are considered "nearfield" (see text).

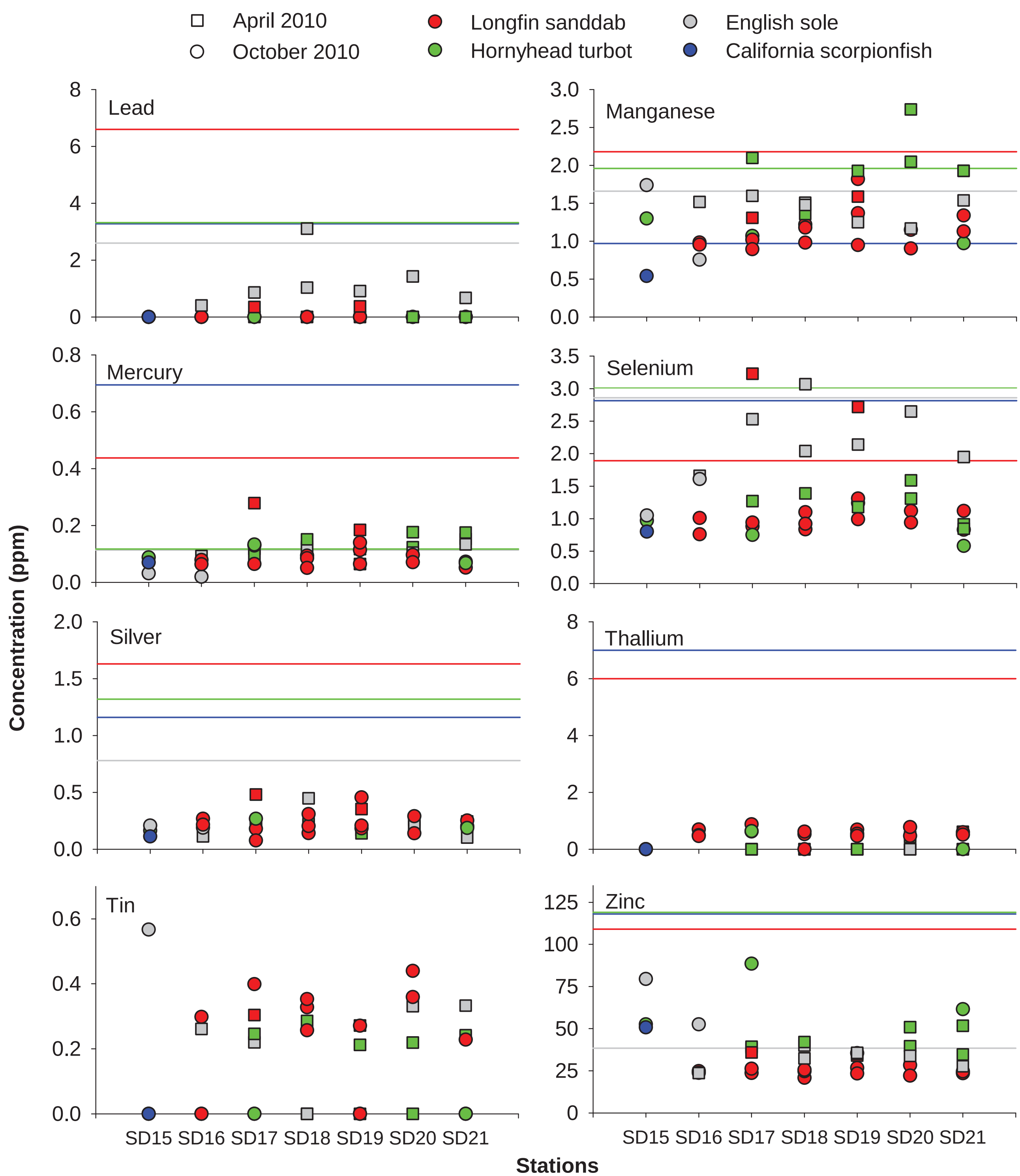


Figure 7.2 *continued*

Contaminants in Fishes Collected by Rig Fishing

Arsenic, copper, mercury, selenium, and zinc occurred in 100% of the muscle tissue samples collected from the two rig fishing stations in 2010 (Table 7.4). Aluminum and thallium were only detected in 50–58% of the samples, while barium, beryllium, chromium, iron, lead and tin were detected in 33% or less of the samples. Antimony, cadmium, manganese, nickel and silver were never detected. The metals present in the highest concentrations were aluminum (up to 11.5 ppm), zinc (up to 6.3 ppm), arsenic (up to 3.4 ppm), and iron (up to 2.7 ppm). Overall, concentrations of these contaminants were fairly similar between each rig fishing station and occurred in concentrations less than those measured in the same species prior to discharge (Figure 7.4). Exceptions to this included aluminum, arsenic, mercury and zinc, each of which exceeded pre-discharge maxima in at least one sample (out of 12 total), primarily at station RF4.

Total DDT, composed primarily of p,p-DDE, was detected in 100% of the muscle samples, while the pesticide HCB was detected in only 33% (Table 7.5). Concentrations of pesticides ranged from < 1 ppb for HCB to 17.8 ppb for tDDT. These concentrations were less than pre-discharge values, with no clear relationship with proximity to the outfall (Figure 7.3). PCBs were detected in 92% of the muscle samples, at concentrations up to 12.3 ppb. The congener PCB 153/168 was the most frequently detected, occurring in every muscle sample containing PCBs, while another 20 congeners were detected in ≤42% of the samples (Appendix F.3).

Most of the contaminants detected in fish muscle tissues in 2010 occurred at concentrations below state, national, and international limits and standards (Tables 7.4, 7.5). Only arsenic and selenium were detected in concentrations higher than median international standards, while mercury (as a proxy for methylmercury) and tPCB exceeded OEHHA fish contaminant goals. Exceedances for arsenic occurred in both California scorpionfish and mixed rockfish muscle samples, while exceedances for selenium occurred in scorpionfish, mixed rockfish, and brown rockfish. The exceedances for mercury were detected in both brown rockfish and California scorpionfish, while the exceedances for tPCB occurred only in scorpionfish.

Discussion

Fish are often highly mobile depending on species or life-history stage, and the area in which an individual is caught may only represent a tiny fraction of the geographic area in which it lives. For example, it has been previously reported that California scorpionfish tagged in Santa Monica Bay near Los Angeles have been recaptured as far south as the Coronado Islands in Mexico (Hartmann 1987, Love et al. 1987). Therefore, even though an individual fish may have been caught

Table 7.3

Summary of pesticides, tPCB, tPAH, and lipids in liver tissues of fishes collected at SBOO trawl stations during 2010. Data include the number of detected values (*n*), minimum, maximum, and mean* detected concentrations for each species, and the detection rate and max value for all species. Data are expressed in ppb for all parameters except lipids, which are presented as % weight; the number of samples per species is indicated in parentheses; See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for tDDT, tPCB, and tPAH.

	Pesticides				
	HCB	tDDT	tPCB	tPAH	Lipids
California scorpionfish					
n (out of 1)	0	1	1	0	1
Min	nd	78	98.0	nd	14.2
Max	nd	78	98.0	nd	14.2
Mean	—	78	98.0	—	14.2
English sole					
n (out of 9)	6	9	9	0	9
Min	nd	11	24.5	nd	0.5
Max	5.9	300	123.8	nd	21.1
Mean	3.0	100	56.7	—	7.8
Hornyhead turbot					
n (out of 10)	2	10	10	0	10
Min	nd	9	4.4	nd	2.9
Max	2.5	104	40.6	nd	11.0
Mean	2.3	54	25.8	—	6.3
Longfin sanddab					
n (out of 16)	15	16	16	1	16
Min	nd	70	82.0	nd	6.5
Max	5.0	287	465.9	41.9	39.2
Mean	3.9	172	232.0	41.9	26.0
All Species:					
Detection Rate (%)	64	100	100	3	100
Max Value	5.9	300	465.9	41.9	39.2

nd = not detected

* Minimum and maximum values were calculated based on all samples, whereas means were calculated on detected values only.

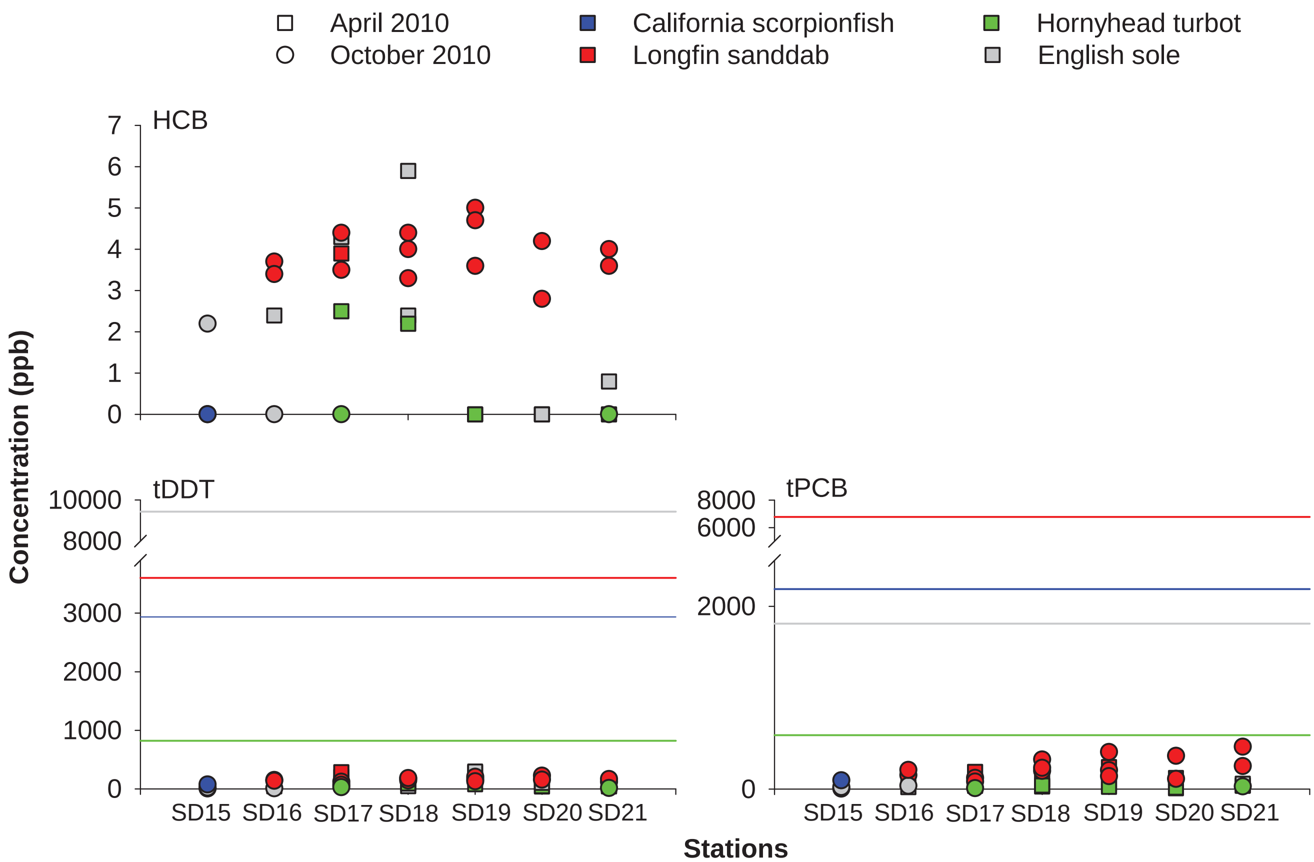


Figure 7.3

Concentrations of HCB, tDDT, and tPCBs in liver tissues of fishes collected from each SBOO trawl station during 2010. Reference lines are maximum values detected during the pre-discharge period (1995–1998) for each species; HCB was not detected in tissue from these species during the pre-discharge period because of substantially higher detection limits; therefore, reference lines for this contaminant are absent. To differentiate between missing values (i.e., samples that were not collected or not analyzed; see Table 7.1) and non-detects, zeros were added as placeholders for non-detected values. Stations SD17 and SD18 are considered "nearfield" (see text).

near the South Bay outfall, any tissue contaminants it contains are likely bioaccumulated over a broad geographic area. It is therefore difficult to attribute the contaminant loading in the liver or muscle tissue of fishes collected in the SBOO region to discharge of wastewater from the outfall.

During 2010, several trace metals, the pesticides DDT and HCB, PAHs and PCBs were detected in liver tissue samples from four species of fish collected in the SBOO region. Many of the same metals, pesticides and PCBs were also detected in muscle tissues during the year, although often less frequently and/or in lower concentrations. Tissue contaminant values ranged widely within and among species and stations. However, all were within the range of values reported previously for the Southern California Bight (SCB) (Mearns et al. 1991, City of San Diego 1996–2001, Allen et al. 1998). In addition, while some muscle tissue samples from sport fish collected in the area exhibited concentrations of arsenic and selenium above the median international standard for shellfish, and some had concentrations of mercury and PCBs that exceeded OEHHA fish contaminant goals, concentrations of mercury and DDT were below USFDA human consumption limits.

The frequent occurrence of metals and chlorinated hydrocarbons in fish tissues are likely due to multiple factors. For instance, Mearns et al. (1991) described the distribution of several contaminants, including arsenic, mercury, DDT, and PCBs as being ubiquitous in the SCB, and not unique to

Table 7.4

Summary of metals in muscle tissues of fishes collected at SBOO rig fishing stations during 2010. Data include the number of detected values (*n*), minimum, maximum, and mean* detected concentrations for each species, and the detection rate and maximum value for all species. Concentrations are expressed as parts per million (ppm); the number of samples per species is indicated in parentheses. Bold values meet or exceed OEHHA fish contaminant goals, USFDA action limits, or median international standards (IS). See Appendix F.2 for MDLs and names for each metal represented by periodic table symbol.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
Brown rockfish																		
n (out of 5)	2	0	5	0	0	0	1	5	0	0	0	5	0	5	0	3	2	5
Min	nd	nd	0.59	nd	nd	nd	nd	0.12	nd	nd	nd	0.08	nd	0.16	nd	nd	nd	2.4
Max	6.7	nd	1.22	nd	nd	nd	0.14	0.43	nd	nd	nd	**0.25**	nd	**0.32**	nd	0.66	0.23	4.8
Mean	6.3	—	0.91	—	—	—	0.14	0.31	—	—	—	0.17	—	0.23	—	0.51	0.22	3.5
California scorpionfish																		
n (out of 6)	3	0	6	1	1	0	3	6	3	0	0	6	0	6	0	4	2	6
Min	nd	nd	1.36	nd	nd	nd	nd	0.15	nd	nd	nd	0.10	nd	0.19	nd	nd	nd	2.8
Max	11.5	nd	**3.40**	0.06	0.01	nd	0.14	0.43	2.7	nd	nd	**0.40**	nd	**0.61**	nd	0.56	0.33	6.3
Mean	7.8	—	**2.45**	0.06	0.01	—	0.13	0.30	2.5	—	—	0.20	—	**0.35**	—	0.50	0.30	3.8
Mixed rockfish	1	0	1	0	0	0	0	1	0	1	0	1	0	1	0	0	0	1
n (out of 1)	10.9	nd	**1.50**	nd	nd	nd	nd	1.16	nd	0.21	nd	0.15	nd	**0.32**	nd	nd	nd	4.5
Min	10.9	nd	**1.50**	nd	nd	nd	nd	1.16	nd	0.21	nd	0.15	nd	**0.32**	nd	nd	nd	4.5
Max	10.9	—	**1.50**	—	—	—	—	1.16	—	0.21	—	0.15	—	**0.32**	—	—	—	4.5
Mean																		
All species:																		
Detection Rate (%)	50	0	100	8	8	0	33	100	25	8	0	100	0	100	0	58	33	100
Max Value	11.5	nd	**3.40**	0.06	0.01	nd	0.14	1.16	2.7	0.21	nd	**0.40**	nd	**0.61**	nd	0.66	0.33	6.3
OEHHA**	na	na	na	na	na	na	na	na	na	na	na	0.22	na	7.4	na	na	na	na
USFDA Action Limit***	na	na	na	na	na	na	na	na	na	na	na	1	na	na	na	na	na	na
Median IS***	na	na	1.4	na	na	na	1	20	na	na	na	0.5	na	0.3	na	na	175	70

na = not available; nd = not detected

* Minimum and maximum values were calculated based on all samples, whereas means were calculated on detected values only.

** From the California OEHHA (Klasing and Brodberg 2008).

*** From Mearns et al. 1991. USFDA mercury action limits and all international standards (IS) are for shellfish, but are often applied to fish.

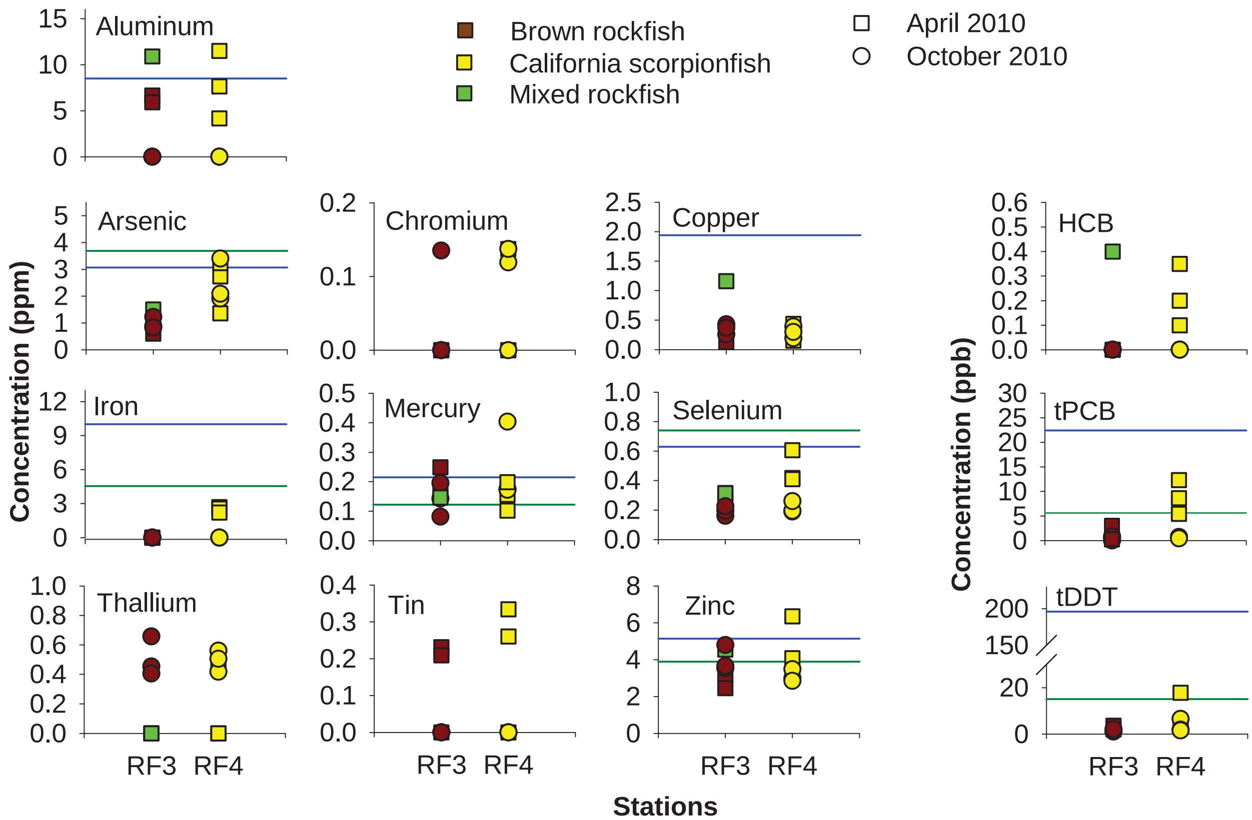


Figure 7.4

Concentrations of frequently detected metals, HCB, tDDT, and tPCB in muscle tissues of fishes collected from each SBOO rig fishing station during 2010. Reference lines are maximum values detected during the pre-discharge period (1995–1998) for California scorpionfish and mixed rockfish; brown rockfish were not collected during that period. All missing values = non-detects. Station RF3 is considered "nearfield" (see text).

the SBOO region. In fact, many metals occur naturally in the environment, although little information is available on background levels in fish tissues. Brown et al. (1986) determined that no areas of the SCB are sufficiently free of chemical contaminants to be considered reference sites. This has been supported by more recent work examining PCBs and DDTs (Allen et al. 1998, 2002). The lack of contaminant-free reference areas in the SCB clearly pertains to the South Bay outfall region, as demonstrated by the presence of many contaminants in fish tissues prior to wastewater discharge (City of San Diego 2000b).

In addition to distributional differences of contaminants in the environment, physiological accumulation and distribution of these contaminants differ among species or even among individuals from different life history stages of a single species (see Groce 2002 and references therein). For example, different species exposed to the same concentrations of a contaminant often differ in the amount of the contaminant that ends up in their tissues. Finally, exposure to contaminants can vary greatly between different species and among individuals of the same species depending on migration habits (Otway 1991). For example, fishes may be exposed to contaminants in an area that is highly contaminated and then migrate into an area that is not. This is of particular concern for fishes collected in the vicinity of the SBOO, as there are many point and non-point sources that may contribute to contamination in the region (see Chapters 2–4); some monitoring stations are located near the Tijuana River, San Diego Bay, and dredged materials disposal sites, and input from these sources may affect fish in surrounding areas.

Overall, there was no evidence that fishes collected in 2010 were contaminated by the discharge of wastewater from the SBOO. Although several individual tissue samples contained concentrations

Table 7.5

Summary of pesticides, tPCB, and lipids in muscle tissues of fishes collected at SBOO rig fishing stations during 2010. Data include the number of detected values (*n*), minimum, maximum, and mean* detected concentrations for each species and the detection rate and max value for all species. Data are expressed in ppb for all parameters except lipids, which are presented as % weight; the number of samples per species is indicated in parentheses. Bold values meet or exceed OEHHA fish contaminant goals, USFDA action limits, or median international standards (IS). See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for tDDT and tPCB.

	Pesticides			
	HCB	tDDT	tPCB	Lipids
Brown rockfish				
n (out of 5)	0	5	4	5
Min	nd	1.0	nd	0.29
Max	nd	3.6	3.0	0.49
Mean	–	2.0	1.2	0.36
California scorpionfish				
n (out of 6)	3	6	6	6
Min	nd	1.5	0.4	0.24
Max	0.35	17.8	**12.3**	1.42
Mean	0.22	5.9	**4.7**	0.70
Mixed rockfish				
n (out of 1)	1	1	1	1
Min	0.40	2.0	0.2	0.55
Max	0.40	2.0	0.2	0.55
Mean	0.40	2.0	0.2	0.55
All Species:				
Detection Rate (%)	33	100	92	100
Max Value	0.40	17.80	**12.3**	1.42
OEHHA**	na	21	3.6	na
U.S. FDA Action Limit***	na	5000	na	na
Median IS***	na	5000	na	na

na = not available; nd = not detected

* Minimum and maximum values were calculated based on all samples, whereas means were calculated on detected values only.

** From the California OEHHA (Klasing and Brodberg 2008).

*** From Mearns et al. 1991. USFDA action limits and all international standards (IS) are for shellfish, but are often applied to fish.

of some metals that exceeded pre-discharge maxima, concentrations of most contaminants were not substantially different from pre-discharge levels (City of San Diego 2000b). In addition, most of the tissue samples that did exceed pre-discharge values were widely distributed among the sampled stations and showed no patterns that could be attributed to wastewater discharge. Finally, there was no other indication of poor fish health in the region, such as the presence of fin rot, other indicators of disease, or any physical anomalies (see Chapter 6).

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Chapter 8
San Diego Regional Survey
Sediment Conditions

Chapter 8. San Diego Regional Survey Sediment Conditions

INTRODUCTION

Ocean sediments are the primary habitat for macrobenthic invertebrate and demersal fish communities on the coastal shelf and slope. The physical and chemical conditions of these sediments can therefore influence the ecological health of marine communities by affecting the distribution and presence of various species (Gray 1981, Cross and Allen 1993, Snelgrove and Butman 1994). For this reason, sediments have been sampled extensively near Southern California Bight (SCB) ocean outfalls in order to monitor benthic conditions around these and other point sources over the past several decades (Swartz et al. 1986, Anderson and Gossett 1987, Finney and Huh 1989, Stull 1995, Bay and Schiff 1997). While such localized assessments are ongoing for the four largest wastewater dischargers in the region (see City of Los Angeles 2007, 2008, City of San Diego 2010a, b, LACSD 2010, OCSD 2011), larger-scale monitoring efforts from Point Conception to the Mexican border have also become an important tool for evaluating overall sediment conditions in the SCB (Schiff and Gossett 1998, Noblet et al. 2003, Schiff et al. 2006).

The City of San Diego has conducted annual regional benthic surveys off the coast of San Diego since 1994 (see Chapter 1). The primary objectives of these summer surveys, which typically range from Del Mar to the USA/Mexico border, are to (1) describe the overall condition and quality of the diverse benthic habitats that occur off San Diego, (2) characterize the ecological health of the soft-bottom marine benthos in the region, and (3) gain a better understanding of regional variation in order to distinguish anthropogenically-driven changes from natural fluctuations. These surveys typically occur at an array of 40 stations selected each year using a probability-based, random stratified sampling design as described in Bergen (1996), Stevens (1997), and Stevens and Olsen (2004). During 1995–1997, 1999–2002 and 2005–2007, the surveys off San Diego were restricted to continental shelf depths (<200 m), while the area of coverage was expanded in 2009 and 2010 to also include deeper habitats along the upper slope (200–500 m). No survey of randomly selected sites was conducted in 2004 due to sampling for a special sediment mapping project (Stebbins et al. 2004), while surveys in 1994, 1998, 2003 and 2008 were conducted as part of larger, multi-agency surveys of the entire SCB (Schiff and Gossett 1998, Noblet et al. 2003, Schiff et al. 2006, Maruya and Schiff 2009).

This chapter presents results of the analysis and interpretation of sediment particle size and chemistry data collected during the 2010 regional survey of continental shelf and upper slope benthic habitats off San Diego. Included are descriptions of the region's sediment conditions during the year, and comparisons of sediment characteristics and quality across the major depth strata defined by the SCB regional programs. Results of the macrofaunal community assessment for these same sites are presented in Chapter 9.

Materials and Methods

Field Sampling

The July 2010 regional survey covered an area ranging from off Del Mar in northern San Diego County south to the USA/Mexico border (Figure 8.1). A total of 40 sites were selected for the survey based on the United States Environmental Protection Agency (USEPA) probability-based Environmental Monitoring and Assessment Program (EMAP) sampling design. These stations ranged in depth from 9 to 433 m, and spanned four distinct depth strata as characterized by the SCB Regional Monitoring Programs (Schiff et al. 2006). These included 8 stations along the inner shelf (5–30 m), 19 stations along the mid-shelf (30–120 m), 6 stations along the outer shelf (120–200 m), and 7 stations on the upper slope (200–500 m).

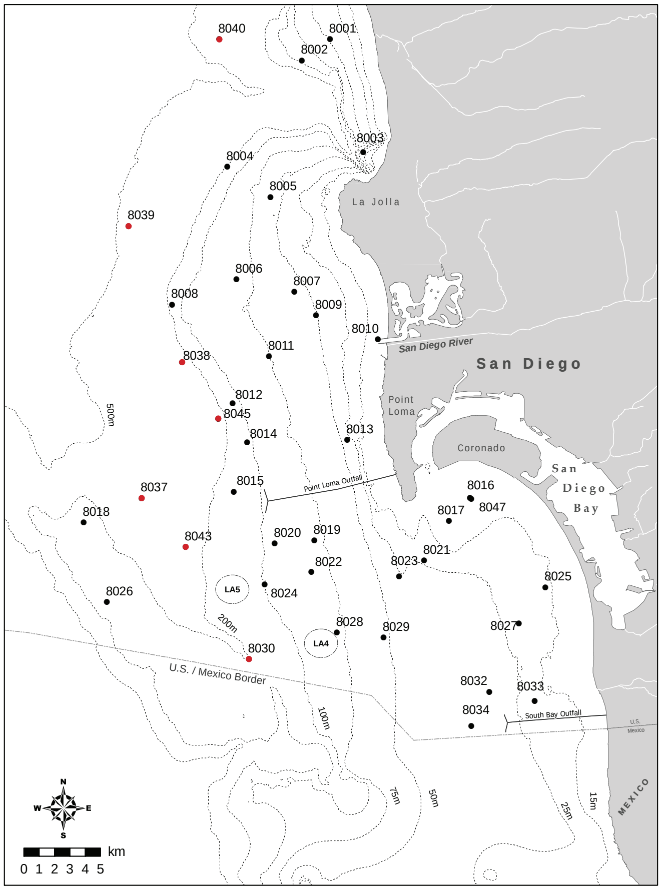

Figure 8.1
Regional benthic survey stations sampled during July 2010 as part of the South Bay Ocean Outfall Monitoring Program. Black circles represent shelf stations and red circles represent slope stations.

Each sediment sample was collected from one side of a chain-rigged double Van Veen grab with a 0.1-m^2 surface area; the other grab sample from the cast was used for macrofaunal community analysis (see Chapter 9) and visual observations of sediment composition. Sub-samples for various analyses were taken from the top 2 cm of the sediment surface and handled according to standard guidelines available in USEPA (1987).

Laboratory Analyses

All sediment chemistry and particle size analyses were performed at the City of San Diego's Wastewater Chemistry Services Laboratory. Particle size analysis was performed using either a Horiba LA-920 laser scattering particle analyzer or a set of six nested sieves. The Horiba analyzer measures particles ranging in size from 0.00049 mm to 2.0 mm (i.e., 11 to -1 phi). Coarser sediments from these samples were removed prior to laser analysis by screening the samples through a 2.0 mm mesh sieve. These data were later combined with the Horiba results to obtain a complete distribution of particle sizes totaling 100%. When a sample contained substantial amounts of coarse materials (e.g., coarse sand, gravel, shell hash) which would damage the Horiba analyzer and/or where the general distribution of sediment sizes would be poorly represented by laser analysis, a set of six nested sieves was instead used to separate the grain size fractions. The mesh sizes of the sieves are 2.0 mm, 1.0 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.063 mm, and separate a seventh fraction of all particles finer than 0.063 mm. In the 2010 regional survey, 36 samples were processed by laser analysis and four samples (8013, 8023, 8024, 8033) were processed by sieve analysis. Results from the sieve analysis and output from the Horiba were categorized into phi sizes based on the Wentworth scale (Appendix C.1). These phi sizes were then used in the calculation of various particle size parameters, which were determined using a normal probability scale (see Folk 1980). Summaries of particle size parameters included overall mean particle size (mm), phi size (mean, standard deviation, skewness, kurtosis), and the proportion of coarse, sand, silt, and clay. Additionally, the proportion of fine particles (percent fines) was calculated as the sum of all silt and clay fractions for each sample.

Each sediment sample was chemically analyzed to determine concentrations of total organic carbon (TOC), total nitrogen (TN), total sulfides, biochemical oxygen demand (BOD), total volatile solids (TVS), trace metals, chlorinated pesticides (e.g., DDT), polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs) on a dry weight basis (see Appendix C.2). TOC, TN, and TVS were measured as percent weight (% wt) of the sediment sample; BOD, sulfides, and metals were measured in units of mg/kg and are expressed in this report as parts per million (ppm); pesticides and PCBs were measured in units of ng/kg and are expressed as parts per trillion (ppt); PAHs were measured in units of µg/kg and are expressed as parts per billion (ppb). Reported values were generally limited to values above the method detection limit (MDL) for each parameter. However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry. A more detailed description of the analytical protocols is provided by the Wastewater Chemical Services Laboratory (City of San Diego 2011).

Data Analyses

Data summaries for the various sediment parameters measured during 2010 included detection rates, annual means of detected values for all stations combined (areal mean), and minimum, median, and maximum values during the year. Total chlordane, total DDT (tDDT), total HCH (tHCH), total PCB (tPCB), and total PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values (see Appendix G.1 for individual constituent values). Statistical analyses included Spearman rank correlation of percent fines with each chemical parameter. This non-parametric analysis accommodates non-detects (i.e., analyte concentrations measured below the MDL) without the use of value substitutions (Helsel 2005). However, depending on the data distribution, the instability in ranked-based analyses may intensify with increased censoring (Conover 1980). Therefore, a criterion of <50% non-detects was used to screen eligible constituents for this analysis. In addition, only parameters analyzed with a single MDL throughout the entire year were considered for correlation analysis (Helsel 2005). Correlation results were confirmed visually by graphical analyses.

Data from the 2010 surveys were compared to the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines of Long et al. (1995) when available to assess contamination levels. The National Status and Trends Program of the National Oceanic and Atmospheric Administration (NOAA) originally established the ERLs and ERMs to provide a means for interpreting environmental monitoring data. The ERLs represent chemical concentrations below which adverse biological effects are rarely observed. Values above the ERL but below the ERM represent values at which effects occasionally occur. Concentrations above the ERM indicate likely biological effects, although these are not always validated by toxicity testing (Schiff and Gossett 1998). Contamination levels were further evaluated by comparing results for the current year with historical data, including comparisons between the maximum values for 2010 to those from the pre-discharge period (i.e., 1991–1993).

Multivariate analyses were performed using PRIMER software (Plymouth, UK, 2006) to further explore spatial patterns in regional sediment conditions in 2010. A subset of particle size (e.g., median phi, sorting, percent fines) and chemistry parameters were first normalized and then analyzed by agglomerative hierarchical clustering using Euclidean distances as the basis for classification (Clarke and Gorley 2006). Chemistry parameters were selected for analysis which had detection rates ≥25%; zeros were substituted for non-detects before analysis. The non-random structure of the dendrogram resulting from cluster analysis was evaluated using similarity profile analysis (SIMPROF), and non-metric multidimensional scaling (nMDS) was used to visualize sample clustering in multivariate space. Specific parameters driving cluster group similarity and dissimilarity were identified using the 'similarity percentages' routine (SIMPER).

Results

Particle Size Distribution

As in previous surveys (e.g., City of San Diego 2010b), overall particle size composition of sediments off San Diego in 2010 consisted primarily of sands and fine particles (Table 8.1). In addition, visual observations of the sediments sampled from throughout the region revealed the presence of several unique types of sands and coarse materials including red relict sand, coarse black sand, gravel, and organic debris (Appendix G.2). The relative

Table 8.1

Summary of particle size and sediment chemistry parameters at regional benthic stations during 2010. Data include detected values averaged by depth stratum, as well as the detection rate, minimum, median, maximum, and mean values for the entire survey area. *n* = number of stations; SD = standard deviation.

	Depth Strata				2010 Survey Area*				
	Inner Shelf (5–30 m) *n* = 8	Mid-shelf (30–120 m) *n* = 19	Outer Shelf (120–200 m) *n* = 6	Upper Slope (200–500 m) *n* = 7	Detection Rate (%)	Min	Median	Max	Mean
Particle Size									
Mean (*mm*)	0.168	0.218	0.085	0.031	**	0.023	0.063	0.786	0.155
Mean (*phi*)	2.68	3.18	3.78	5.06	**	0.35	3.99	5.46	3.50
SD (*phi*)	0.75	1.35	1.68	1.69	**	0.49	1.50	1.97	1.34
Coarse (*%*)	2.4	6.6	0.7	0.0	**	0.0	0.0	43.1	3.7
Sand (*%*)	92.6	63.0	64.2	31.3	**	20.1	63.9	99.5	63.6
Fines (*%*)	5.0	30.4	35.1	68.7	**	0.0	34.6	79.9	32.7
Organic Indicators									
Sulfides (*ppm*)	3.22	4.45	6.23	10.27	93	nd	3.39	24.10	5.64
TN (*% weight*)	0.018	0.057	0.072	0.166	100	0.010	0.055	0.222	0.070
TOC (*% weight*)	0.104	0.808	1.692	2.014	100	0.022	0.604	4.470	1.011
Trace Metals (*ppm*)									
Aluminum	3156	7200	6738	14,107	100	1020	7320	19,400	7531
Antimony	0.43	0.49	0.52	0.89	70	nd	0.42	2.17	0.59
Arsenic	1.43	3.52	3.59	3.28	100	1.11	2.96	6.41	3.07
Barium	17.27	39.60	43.42	73.09	100	1.93	46.65	100.00	41.57
Beryllium	0.04	0.15	0.23	0.30	85	nd	0.16	0.37	0.18
Cadmium	0.06	0.15	0.20	0.39	73	nd	0.13	0.62	0.22
Chromium	7.1	15.1	21.4	28.3	100	3.5	17.5	33.4	16.7
Copper	2.63	8.32	7.37	19.61	100	0.29	7.09	31.20	9.02
Iron	4286	11,226	13,512	17,271	100	3170	12,250	21,400	11,239
Lead	2.29	9.51	4.24	6.33	100	0.89	4.65	91.60	6.72
Manganese	45.3	92.2	64.8	122.5	100	8.2	93.1	235.0	84.0
Mercury	0.018	0.032	0.023	0.052	83	nd	0.024	0.089	0.033
Nickel	1.69	6.04	6.87	16.11	100	0.77	6.06	21.20	7.06
Selenium	—	0.361	0.364	0.827	60	nd	0.268	1.160	0.498
Silver	0.30	0.33	—	—	5	nd	nd	0.33	0.31
Thallium	2.0	—	—	—	3	nd	nd	2.0	2.0
Tin	0.4	0.9	0.7	1.4	80	nd	0.8	2.6	0.9
Zinc	10.1	28.3	28.7	47.8	100	3.9	31.3	58.8	28.2
Pesticides (*ppt*)									
Total HCH	—	—	8500	—	3	nd	nd	8500	8500
Total DDT	—	8000	1307	218	48	nd	nd	75,920	4486
HCB	50	57	—	—	10	nd	nd	81	55
Total PCB (*ppt*)	—	1219	—	3813	20	nd	nd	7335	1867
Total PAH (*ppb*)	—	65.6	—	—	8	nd	nd	101.0	65.6

nd = not detected

* Minimum, median, and maximum values were calculated based on all samples (*n* = 40), whereas means were calculated on detected values only (*n* ≤ 40).

** Particle size parameters calculated for all samples.

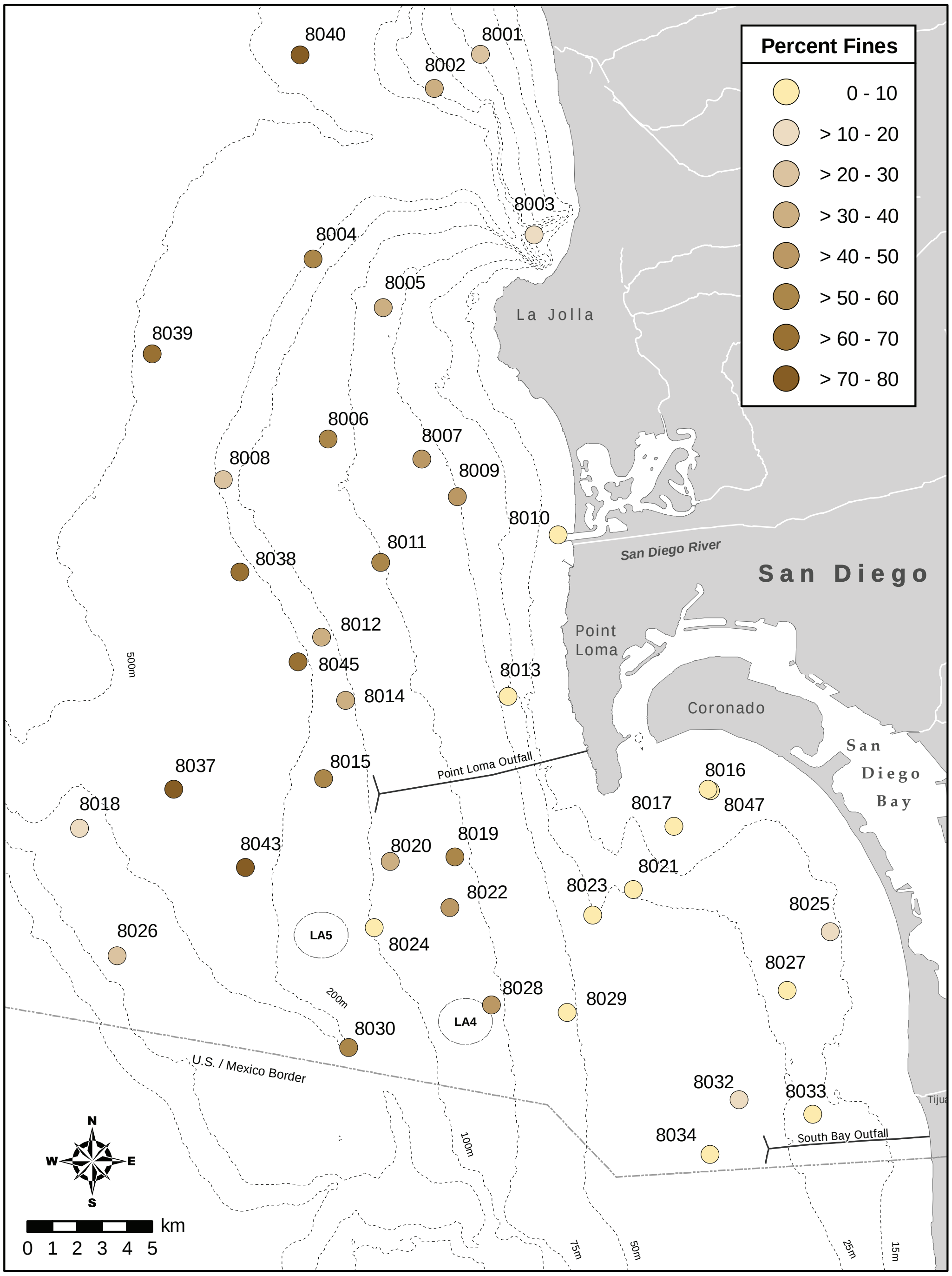

Figure 8.2
Distribution of fine sediments (percent fines) at regional benthic stations sampled during July 2010.

contribution of each particle size fraction varied between stations and by depth strata (Figure 8.2, Appendix G.3). For example, the eight sites located in shallow water along the inner shelf (i.e., ≤30 m) averaged about 5% fines, 93% sands, and 2% coarser particles, whereas the 19 sites located mid-shelf at depths between 31–112 m were characterized by finer sediments of about 30% fines. These results are similar to results of sediment analyses conducted at the SBOO fixed-grid monitoring stations at shallow and mid-shelf depths (see Chapter 4). The six regional sites located on the outer shelf at 123–196 m averaged 35% fines, while the seven sites located along the upper slope at depths >200 m contained the finest sediments of the region (i.e., 69% fines, 31% sands

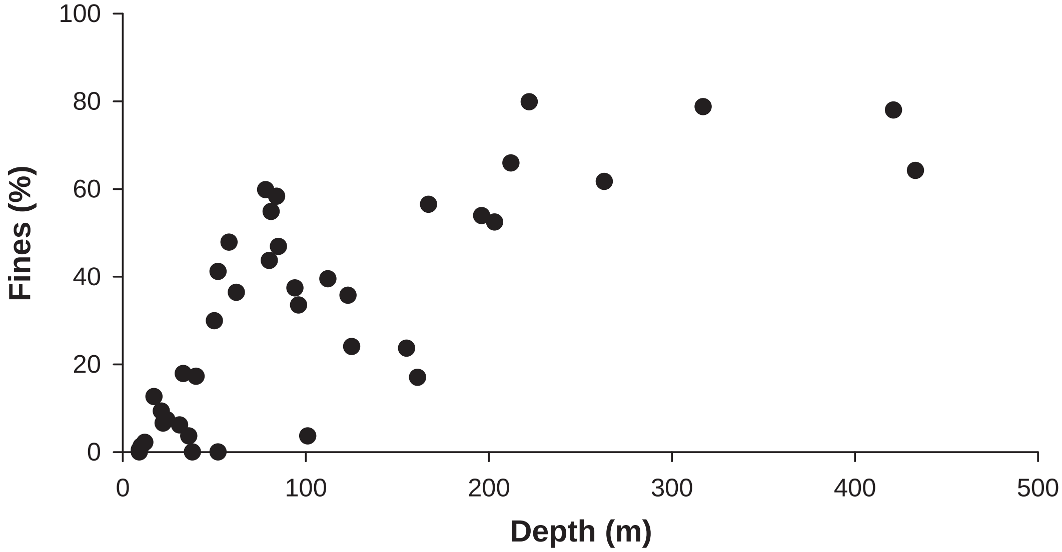

Figure 8.3
Scatterplot of percent fines and depth for regional benthic stations sampled in 2010.

and no coarse fraction). Correlation analysis confirmed that percent fines increased significantly with depth (Spearman Rank correlation coefficient $r_s(40) = 0.78$; $p < 0.001$.; Figure 8.3). The only notable exceptions to this pattern occurred at mid-shelf station 8024 (located ~900 m inshore of the LA-5 dredge material disposal site) and outer shelf station 8018 (located on the Coronado Bank), each of which had lower percent fines than other stations at similar depths (Appendix G.2).

The sorting coefficient is calculated as the standard deviation (SD) in phi size units for each sample, therefore reflecting the range of particle sizes present, and is considered indicative of the level of disturbance (e.g., fluctuating or variable currents and sediment deposition) in an area. Regional sediments ranged from well to poorly sorted, with sorting coefficients ranging from 0.5 to 2.0 (Appendices G.2, G.3). Sediments at shallow stations tended to be well to moderately sorted, with sorting generally decreasing (i.e., becoming more poorly sorted) with depth. These results are consistent with those from the regular SBOO monitoring survey (see Chapter 4). The most well sorted sediments (i.e., with the lowest sorting coefficients) were collected from shallow shelf station 8010, located near the mouth of Mission Bay, and mid-shelf station 8029. These low sorting coefficients are indicative of consistent moderate currents. Stations 8018 and 8030 located on or near the Coronado Bank had the most poorly sorted sediments in the region, which is indicative of more variable currents and sediment transport.

Organic Indicators

Sulfides were detected in 93% of the 2010 regional sediment samples, with average concentrations increasing with each depth stratum. For example, sulfide concentrations averaged about 3.2 ppm at the inner shelf stations, 4.5 ppm at the mid-shelf stations, 6.2 ppm at the outer shelf stations, and 10.3 ppm at upper slope stations (Table 8.1). The highest sulfide concentration (24.1 ppm) was detected at outer shelf station 8015 (Appendix G.4). Several additional stations located throughout the region on the mid-shelf (i.e., 8003, 8013) and upper slope (i.e., 8037, 8038, 8040, 8043, 8045) also contained sediments with relatively high sulfide concentrations (e.g., 10.4–17.5 ppm). Generally, region-wide sulfide concentrations from this study were consistent with those reported for the fixed-grid stations within the SBOO monitoring area (see Chapter 4).

Concentrations of another organic indicator, TN, increased significantly with the proportion of fine sediments in each sample (Table 8.2, Figure 8.4A). Similarly, concentrations of TN

Table 8.2

Results of Spearman rank correlation analyses of percent fines and sediment chemistry parameters from regional benthic samples collected in 2010. Shown are analytes that had correlation coefficients $r_s(40) \geq 0.70$. For all analyses, $p < 0.001$. The strongest correlations with organic indicators and trace metals are illustrated graphically in Figure 8.4 below.

Analyte	r_s
Organic Indicators (% weight)	
Total Nitrogen	0.95
Trace Metals (ppm)	
Aluminum	0.82
Barium	0.78
Beryllium	0.86
Cadmium	0.71
Chromium	0.84
Copper	0.83
Iron	0.73
Lead	0.75
Mercury	0.78
Nickel	0.95
Selenium	0.82
Tin	0.76
Zinc	0.86

tended to increase across depths. For example, TN ranged from 0.02% wt at the inner shelf stations to 0.17% wt at the upper slope stations on average (Table 8.1). The highest TN concentrations occurred at upper slope stations 8037 (0.22% wt) and 8043 (0.21% wt) (Appendix G.4). Unlike TN, TOC was not correlated with percent fines, although as with the pattern described for sulfides, it did generally increase across depth strata (i.e., 0.10% wt on the inner shelf to 2.01% wt on the upper slope). Exceptions to this overall pattern occurred at mid-shelf station 8013 and outer shelf station 8008, where TOC concentrations exceeded 4% wt. Concentrations of both TN and TOC measured at regional stations were similar to those measured at the regular fixed-grid SBOO monitoring stations (see Chapter 4).

Trace Metals

Aluminum, arsenic, barium, chromium, copper, iron, lead, manganese, nickel and zinc were detected in all sediment samples collected during the 2010 regional survey (Table 8.1). Antimony, beryllium, cadmium, mercury, selenium and

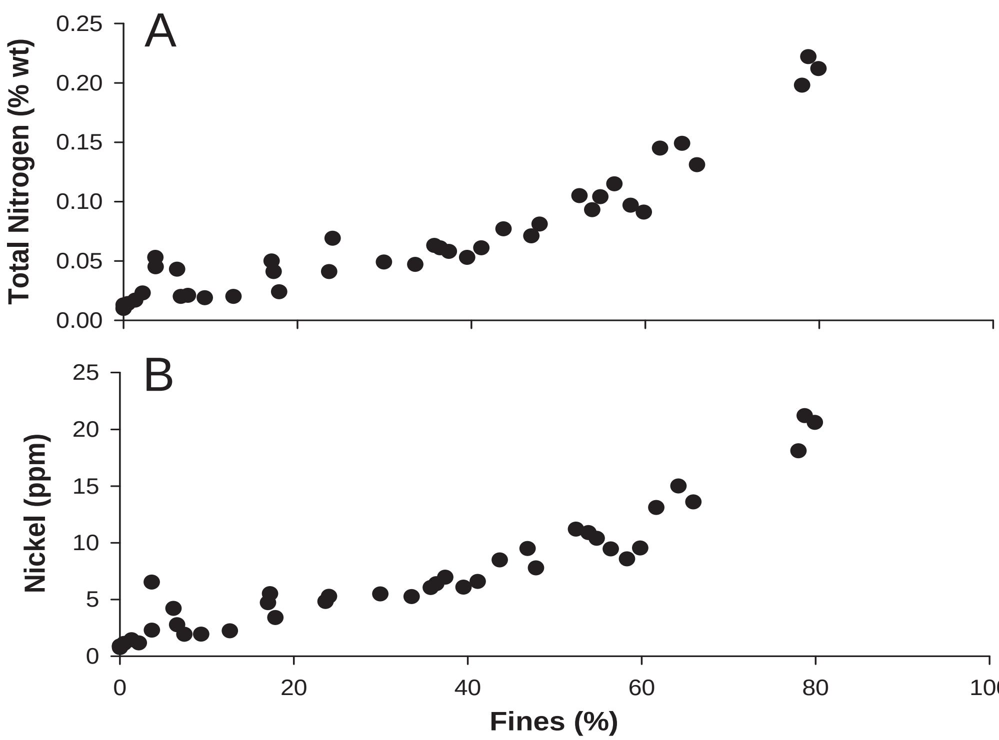

Figure 8.4

Scatterplot of percent fines and concentration of (A) total nitrogen and (B) nickel in regional sediments in 2010.

tin were detected less frequently (e.g., 60–85%), while silver and thallium were detected in fewer than 10% of samples. Concentrations of 13 metals (i.e., aluminum, barium, beryllium, cadmium, chromium, copper, iron, lead, mercury, nickel, selenium, tin, zinc) increased significantly with percent fines (Table 8.2, Figure 8.4B). The highest concentrations of these metals occurred at the deeper, upper slope stations where the greatest percent fines occurred (i.e., stations 8037, 8040, 8043). The single exception to this pattern was for lead, which was detected at its highest concentration of about 92 ppm at inner shelf site 8023 (6.1% fines). As with the regular fixed-grid SBOO monitoring sites, most metal concentrations across the region were below the ERL biological threshold (Appendix G.4). Only two exceptions to this occurred, including: (1) the ERL for lead (46.7 ppm) was exceeded at mid-shelf station 8023 (91.6 ppm); (2) the ERL for nickel (20.9 ppm) was exceeded at upper slope station 8037 (21.2 ppm). None of the samples collected during 2010 had metal concentrations that exceeded ERM thresholds.

Pesticides

Pesticides were detected in approximately half of the regional sediment samples collected during 2010 (Table 8.1, Appendix G.4) at concentrations generally comparable to those found at the regular fixed-grid SBOO monitoring stations. Total DDT (primarily p,p-DDE) was the most prevalent pesticide, occurring in sediments from 48% of the stations at concentrations averaging 8000 ppt along the mid-shelf, 1307 ppt along the outer shelf, and 218 ppt along the upper slope. This pesticide was not detected at inner shelf depths, and only two samples contained concentrations that exceeded threshold values. The latter included sediments from outer shelf station 8012, which contained concentrations of tDDT that exceeded the ERL of 1580 ppt, and sediments from the mid-shelf station 8028 that exceeded the ERM of 46,100 ppt.

Another pesticide, hexachlorobenzene (HCB), occurred in sediments from just 10% of the sites sampled during 2010. This pesticide occurred at four sites located at inner and mid-shelf depths, at concentrations somewhat lower than those found during the SBOO fixed-grid surveys (see Chapter 4). The highest concentration of HCB (81 ppt) occurred on the mid-shelf at station 8022. In addition, the pesticide hexachlorocyclohexane (HCH) was detected at a single station (8012), located on the outer shelf, at a total concentration of 8500 ppt. This pesticide was not detected during regular SBOO monitoring.

PCBs and PAHs

PCBs were detected in 20% of the regional survey sediment samples during 2010. These compounds were only detected at stations from mid-shelf and upper slope depths (Table 8.1, Appendix G.4). The highest total PCB concentration of 7335 ppt occurred in sediments from station 8045 located along the upper slope. Sediments from stations 8028 and 8024 also contained tPCB concentrations greater than 1200 ppt. The most prevalent congeners detected were PCB 138, PCB 149 and PCB 153/168, each occurring in four or more samples (Appendix G.1). Nineteen additional PCB congeners were detected throughout the region, but only in three samples or fewer for each. In general, regional PCB concentrations were higher than those found at the regular fixed-grid SBOO stations sampled during 2010, where this contaminant was detected in only 4% of samples with an areal mean of 182 ppt (see Chapter 4).

PAHs were detected in only 8% of the sediment samples collected from the regional stations in 2010, at three sites on the mid-shelf (i.e., stations 8019, 8024, and 8028) (Table 8.1, Appendix G.4). Sediments from stations 8024 and 8028 had the highest total PAH concentrations (71 and 101 ppb, respectively). The PAH compounds benzo[A]pyrene and 3,4-benzo(B)fluoranthene were each detected in two sediment samples, whereas the compounds benzo[A]anthracene, benzo[G,H,I]perylene, fluoranthene, and pyrene were each detected only once (Appendix G.1). The low incidence of PAHs detected in sediments sampled during 2010 was consistent with findings from the regular fixed-grid SBOO monitoring where no PAHs were detected.

Classification of Sediment Conditions

Results of ordination and the cluster analysis discriminated five groups of sediment samples (Figure 8.5). These groups (cluster groups A–E) varied in terms of particle size composition and contaminant concentrations, and occurred at sites separated along a general depth gradient (Figure 8.5, Table 8.3). The SIMPROF procedure indicated statistically significant non-random structure of the cluster dendrogram (global test: $\pi = 1.37$, $p < 0.001$) and an nMDS ordination of samples supported the validity of the cluster groups (Figure 8.5B).

SIMPER analysis was used to identify parameters that were characteristic of samples within a cluster group (Table 8.3) and parameters that discriminated between cluster groups (Appendix G.5). Cluster group A comprised four samples collected from upper slope depths which contained the greatest average percent fines, the highest concentrations of organics (i.e., sulfides, TN, TOC), and 12 of the 16 metals included in the analysis (several of which correlate with fines; Table 8.2). These relatively high concentrations of organics and metals also distinguished this cluster group from groups B–E. Cluster group B consisted of a single sample, collected from mid-shelf station 8023, which had a concentration of lead ten times greater than other groups. Cluster group C also consisted of a single sample collected from mid-shelf station 8028. This sample had a concentration of tDDT (75,920 ppt) which was twenty-times higher than other tDDT concentrations measured during the survey (Appendix G.4). Cluster group D comprised 12 sediment samples from the inner and mid-shelf, including the majority of regional samples collected from within the regular SBOO monitoring area. This group was characterized by relatively low concentrations of contaminants. For example, this group contained the lowest average concentrations of TN, TOC, and of 14 of the 16 metals analyzed. Lastly, cluster group E consisted of 22 samples from the mid-shelf, outer shelf, and upper slope. This cluster group contained concentrations of most chemistry parameters that were intermediate relative to those characteristic of groups A and D.

Discussion

Sediment particle size conditions at the regional benthic stations sampled in 2010 were typical for the continental shelf and upper slope off the coast of southern California (Emery 1960), and consistent with results from previous surveys (e.g., City of San Diego 2008, City of San Diego 2010b). These sediments consisted mainly of sands, while silt and clay (percent fines) increased with sample depth. However, several exceptions to this overall pattern occurred throughout the region, particularly along the Coronado Bank, a southern rocky ridge located southwest of Point Loma at a depth of 150–170 m. Sediment composition at stations from this area tend to be coarser than stations at similar depths located off of Point Loma and further to the north. Similarly, much of the additional variability in particle size composition throughout the region may be due to the complexities of seafloor topography and current patterns, both of which affect sediment transport and deposition (Emery 1960, Patsch and Griggs 2007). For example, the presence of red relict sands, and lack of silt or clay, at station 8034 suggests this site receives or retains very little recent sediment deposition. In contrast, several other stations lie within accretion zones of coastal littoral cells and receive more frequent deposition of sands and fine particles. The diverse sediment transport and deposition patterns are further illustrated by the range of sorting coefficients measured in regional sediments in 2010. Well-sorted sediments (i.e., SD $\leq$0.5 phi) tended to occur at the inner shelf and shallow mid-shelf stations and are indicative of areas subject to consistent, moderate currents. In contrast, the most poorly sorted sediments (i.e., SD $\geq$ 1.5 phi) occurred at deeper stations of the outer shelf and upper slope. This level of sorting is typical of areas with fluctuating weak to violent currents or rapid deposition (e.g., resulting from storm surge or dredge material dumping) that often result in highly variable or patchy particle size distributions (Folk 1980).

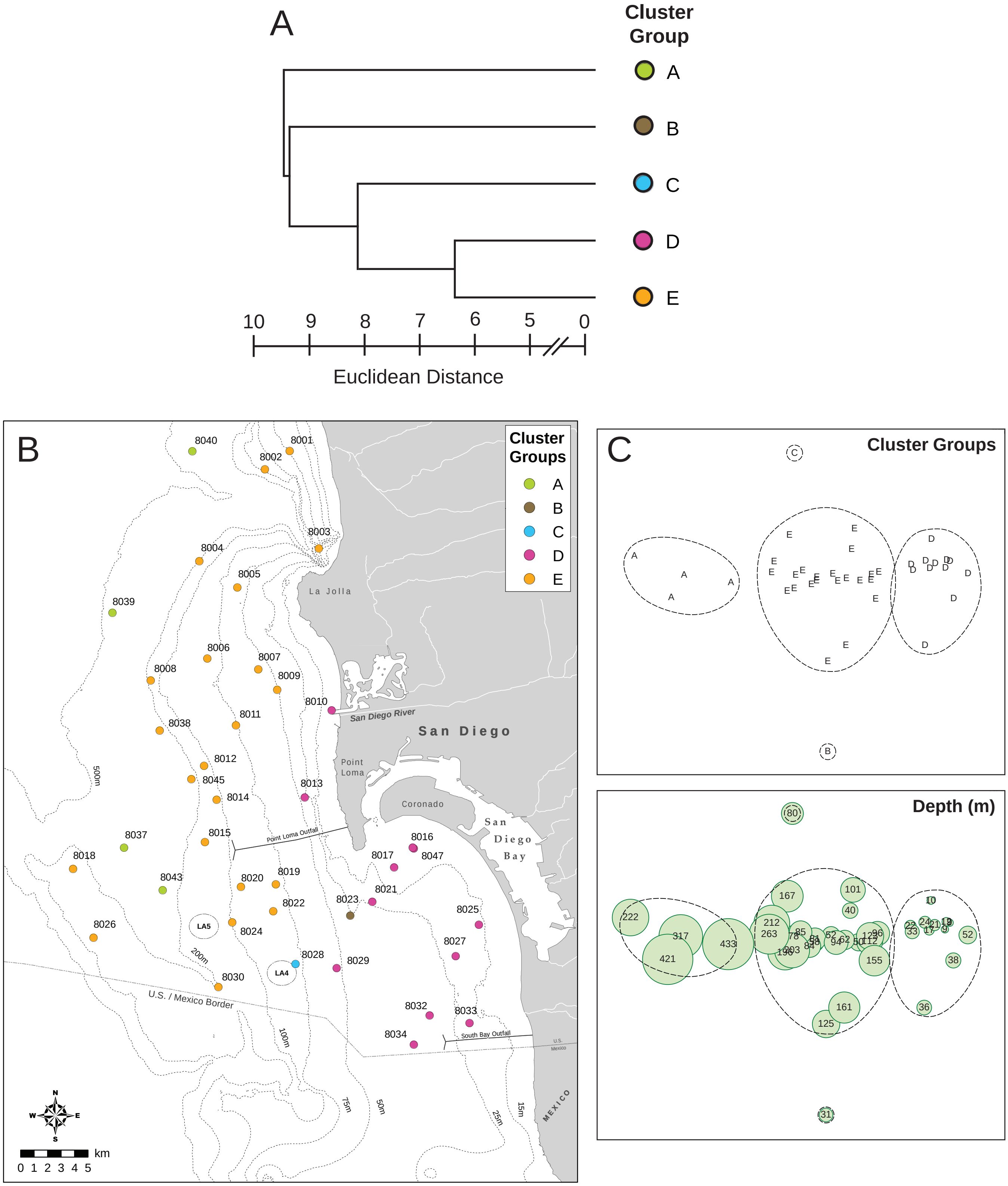

Figure 8.5

Results of multivariate analyses of sediment particle size and chemistry data for the regional benthic statons sampled during 2010. Data are presented as: (A) cluster results; (B) spatial distribution of sediment samples as delineated by cluster analysis; (C) nMDS ordination illustrating distribution of samples in multivariate space. The top panel illustrates the distribution of samples within each group while the lower panel shows a bubble plot of sample depth. nMDS plot stress = 0.08. Dashed ellipses enclose station groups within a Euclidean distance of 6.0.

Table 8.3

Description of cluster groups A–E defined in Figure 8.5. Data include number of samples, average depth (m), and the average percent or concentration of each parameter used in the multivariate analyses, summarized by cluster group. While analyses were conducted on normalised data, average values shown below were calculated using actual values for ease of interpretation. Zeros were substituted for non-detects for the purpose of analysis and data summary (see text). Bold values indicate the three parameters that were considered most characteristic of that group according to SIMPER analysis (i.e., greatest percent contribution to within-group similarity). SD = standard deviation.

	Group A	Group B	Group C	Group D	Group E
Number of Samples	4	1	1	12	22
Depth	348	31	80	24	118
Parameter	**Average Percentage/Concentration**				
Particle Size					
Median *(phi)*	5.4	1.0	3.7	2.2	3.6
SD *(phi)*	1.6	1.4	1.6	**0.8**	1.6
Fines *(%)*	75.2	6.1	43.7	5.1	40.8
Organic Indicators					
Sulfides *(ppm)*	9.38	0.69	3.91	2.55	**6.18**
TN *(% weight)*	0.195	0.043	0.077	0.020	0.076
TOC *(% weight)*	2.318	2.310	0.738	**0.449**	**1.033**
Trace Metals (ppm)					
Aluminum	17,400	4750	12,000	2858	8209
Antimony	**1.20**	0.50	0.60	0.18	0.37
Arsenic	3.41	6.41	3.95	**1.92**	3.45
Barium	87.3	22.5	44.9	15.3	48.3
Beryllium	0.33	0.12	0.19	0.02	0.19
Cadmium	**0.45**	0.17	0.12	0.02	0.18
Chromium	32.1	13.3	18.0	7.5	19.1
Copper	23.8	10.4	15.7	2.6	9.5
Iron	19,250	17,700	12,100	4509	13,120
Lead	7.01	**91.60***	9.36	2.37	5.06
Manganese	139.3	235.0	102.0	39.1	90.8
Mercury	0.066	0.000	0.062	0.008	**0.030**
Nickel	18.7	4.2	8.5	1.7	7.9
Selenium	1.05	0.00	0.28	0.02	0.33
Tin	**1.65**	1.70	1.50	0.12	0.85
Zinc	54.1	39.0	40.9	9.6	32.5
Pesticides (ppt)					
Total DDT	130	0	**75,920***	0	399

*Within-group similarity cannot be calculated for cluster groups consisting of a single sample. However, this parameter distinguished the cluster group from all others in between-group comparisons.

As with the particle size distribution, regional patterns of sediment contamination in 2010 were similar to patterns seen in previous years. For example, concentrations of total nitrogen and several trace metals were found to increase with increasing amounts of fine sediments (percent fines). As percent fines also increased with depth in the region, many contaminants were detected at higher concentrations in deeper strata compared to the shallow and mid-shelf. For example, the highest concentrations of most contaminants occurred in sediments along the upper slope, where some of the finest sediments were measured. Results of the multivariate analyses also confirm this pattern. Sediment samples clustered along a general depth gradient, with the deeper cluster groups containing higher contaminant loads than samples from shallower stations. Exceptions to this included mid-shelf stations 8023 and 8028, which clustered as separate, single-sample groups due to anomalously high lead and tDDT concentrations, respectively, compared to the surrounding region during this survey and previous years (City of San Diego 2007, Maruya and Schiff 2009). Station 8028 also contained the highest levels of PAHs and the second-highest levels of PCBs measured in 2010. This station is located approximately 0.14 km from the LA-4 dredge material disposal site which has been out of use since the early 1980s (USEPA 1988). High levels of various contaminants have historically occurred in sediments from stations located near this site, and/or between the active LA-5 disposal site and San Diego Bay. Although these disposal sites were intended to contain contaminated dredged material in a small area of deep water, "short dumps" have been recorded inshore of LA-5 as far as 2.5 kilometers from the designated site (Gardner et al. 1998). Increased sediment movement in the inshore area of the mid-shelf could result in the re-suspension and transport of contaminated sediments even further from the intended disposal sites (Parnell et al. 2008). Although LA-4 has not been studied as a potential source of contamination in the region, high concentrations of pesticides, PCBs and PAHs in sediments surrounding this location may be indicative of legacy contamination.

Overall, there was no evidence of substantial degradation of sediment quality in the general San Diego region during July 2010. For instance, the ERL biological threshold values for sediment contamination were only exceeded in four samples (i.e., lead at station 8023, nickel at station 8037, and DDT at stations 8012 and 8028). The tDDT concentration measured at station 8028 was also the only exceedance of the ERM biological threshold in regional sediments in 2010. The majority of samples collected during the survey contained relatively low contaminant concentrations for the region (City of San Diego 2007) as well as the greater Southern California Bight (Noblet et al. 2003, Maruya and Schiff 2009).

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Chapter 9
San Diego Regional Survey
Macrobenthic Communities

Chapter 9. San Diego Regional Survey Macrobenthic Communities

INTRODUCTION

Macrobenthic invertebrates fulfill essential roles as nutrient recyclers and bioeroders, and are a source of food for higher trophic levels in marine ecosystems throughout the world, including the Southern California Bight (SCB). Additionally, because of their ability to serve as reliable indicators of pollution or other environmental stressors, benthic macrofauna have been sampled extensively for the past several decades in order to monitor potential changes around SCB ocean outfalls and other point sources at small spatial scales (Stull et al. 1986, 1996, Swartz et al. 1986, Ferraro et al. 1994, Zmarzly et al. 1994, Diener and Fuller 1995, Diener et al., 1995, Stull 1995). Examples of such local assessments include the regular ongoing surveys conducted each year around the ocean outfalls operated by the City of Los Angeles, the City of San Diego, the Los Angeles County Sanitation District, and the Orange County Sanitation District, the four largest wastewater dischargers in the region (City of Los Angeles 2007, 2008, City of San Diego 2010a, b, LACSD 2010, OCSD 2011). In order to place data from these localized surveys into a broader biogeographic context, larger-scale regional monitoring efforts of the entire SBC have also become an important tool for evaluating benthic conditions and sediment quality in southern California (Bergen et al. 1998, 2000, Hyland et al. 2003, Ranasinghe et al. 2003, 2007, USEPA 2004).

The City of San Diego has conducted annual regional benthic surveys off the coast of San Diego since 1994 (see Chapter 1). The primary objectives of these summer surveys, which typically range from Del Mar to the USA/Mexico border, are to (1) describe the overall condition and quality of the diverse benthic habitats that occur off San Diego, (2) characterize the ecological health of the soft-bottom marine benthos in the region, and (3) gain a better understanding of regional variation in order to distinguish anthropogenically-driven changes from natural fluctuations. These surveys typically occur at an array of 40 stations selected each year using a probability-based, random stratified sampling design as described in Bergen (1996), Stevens (1997), and Stevens and Olsen (2004). During 1995–1997, 1999–2002 and 2005–2007, the surveys off San Diego were restricted to continental shelf depths (<200 m), while the area of coverage was expanded in 2009 and 2010 to also include deeper habitats along the upper slope (200–500 m). No survey of randomly selected sites was conducted in 2004 due to sampling for a special sediment mapping project (Stebbins et al. 2004), while surveys in 1994, 1998, 2003 and 2008 were conducted as part of larger, multi-agency surveys of the entire SCB (Bergen et al. 1998, 2001, Ranasinghe et al. 2003, 2007, 2010).

This chapter presents results of the analysis and interpretation of the benthic macrofauna data collected during the 2010 regional survey of the continental shelf and upper slope off San Diego. Included are descriptions and comparisons of the soft-bottom macrobenthic assemblages present and analyses of benthic community structure for the region. Results of benthic sediment quality analyses at the same sites are presented in Chapter 8.

MATERIALS AND METHODS

Collection and Processing of Samples

The July 2010 regional survey covered an area ranging from off Del Mar in northern San Diego County south to the USA/Mexico border (Figure 9.1). Overall, the 2010 survey included 40 stations ranging in depth from 9 to 433 m and spanning four distinct depth strata as characterized by the SCB regional monitoring programs (Ranasinghe et al. 2007). These included 8 stations along the inner shelf (5–30 m), 19 stations along the mid-shelf (30–120 m), 6 stations along the outer shelf (120–200 m), and 7 stations on the upper slope (200–500 m).

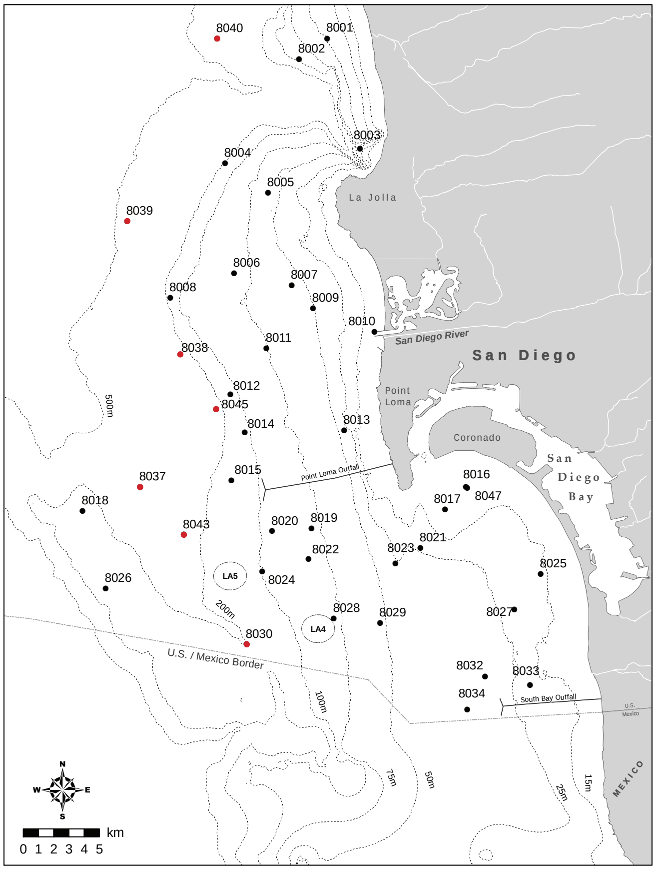

Figure 9.1

Regional benthic survey stations sampled during July 2010 as part of the South Bay Ocean Outfall Monitoring Program. Black circles represent shelf stations and red circles represent slope stations.

At each of the 40 stations, samples for benthic community analysis were collected using a double 0.1-m^2 Van Veen grab; one of the grabs from each cast was used to sample macrofauna, while the adjacent grab was used for sediment quality analysis (see Chapter 8). To ensure consistency of grab samples, protocols established by the United States Environmental Protection Agency (USEPA) were followed to standardize sample disturbance and depth of penetration (USEPA 1987). All samples were sieved aboard ship through a 1.0-mm mesh screen, and organisms retained on the screen were collected and relaxed for 30 minutes in a magnesium sulfate solution before fixing in buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol. All animals were sorted from the debris into major taxonomic groups by a subcontracted laboratory and then identified to species (or the lowest taxon possible) and enumerated by City of San Diego marine biologists.

Data Analyses

The following community metrics were calculated for each station per 0.1-m^2 grab: species richness (number of taxa), abundance (number of individuals), Shannon diversity index (H'), Pielou's evenness index (J'), Swartz dominance (minimum number of taxa accounting for 75% of the total abundance in a sample) (Swartz et al. 1986, Ferraro et al. 1994), and the benthic response index (BRI) developed by Smith et al. (2001). These data are summarized for the inner shelf, mid-shelf, outer shelf, and upper slope depth strata described above for the SCB.

To examine spatio-temporal patterns of benthic macrofaunal assemblages, analyses were performed using PRIMER (Clarke 1993, Warwick 1993, Clarke and Gorley 2006). These analyses included classification (cluster analysis) by hierarchical agglomerative clustering with group-average linking and ordination by non-metric multidimensional scaling (nMDS). Macrofaunal abundance data were square-root transformed, and the Bray-Curtis measure of similarity was used as the basis for classification. Similarity profile analysis (SIMPROF) was used to confirm non-random structure of the resulting dendrograms (Clarke et al. 2008), while the similarity percentages routine (SIMPER) identified species that were characteristic, though not always the most abundant, within assemblages. Patterns in the distribution of the resultant assemblages were subsequently compared to several environmental variables by overlaying the physico-chemical data onto nMDS plots based on the macrofauna data (Field et al. 1982, Clarke and Ainsworth 1993).

Results

Community Parameters

Species richness

A total of 728 macrobenthic taxa (mostly species) were identified during the summer 2010 regional survey. Of these, 267 (~37%) were rare species or unidentifiable taxa (e.g., juveniles or damaged specimens) that occurred only once. Species richness values from all four strata combined ranged from 18–174 species per station, with the range of values found within each stratum overlapping considerably (Table 9.1). However, average species richness values indicated that mid-shelf sites typically possessed a higher number of taxa than other strata, while the inner shelf and upper slope strata both contained sites with the lowest species richness (although species diversity may differ between inner shelf and upper slope locations) (Figure 9.2A).

Macrofaunal abundance

Macrofaunal abundance at the three shelf depths surveyed ranged from 85–811 animals per site, with ranges within each stratum exhibiting significant overlap (Table 9.1). Abundance varied with depth across the shelf, with inner, mid-, and outer shelf assemblages averaging ~275, 382, and 229 animals/grab, respectively (Figure 9.2B). The greatest number of animals documented in 2010 occurred at the relatively shallow mid-shelf stations 8023 and 8032, both of which possessed >800 animals per grab (Table 9.1), and at station 8013 (also a shallow mid-shelf site) which possessed 645 animals per grab. In contrast, upper slope sites exhibited relatively low abundance values ranging from 76–227 animals/site, with an average of 117 animals/site (Table 9.1, Figure 9.2B).

Diversity and evenness

During 2010, diversity (H') ranged from 2.0 to 4.5 across all strata (Table 9.1). Although diversity ranges overlapped among strata, average values indicate that sites along the inner shelf possessed lower diversity than in deeper areas (Figure 9.2C). The eight stations with the highest diversity (i.e., H'≥4.0) occurred predominantly along the mid-shelf stratum, although one outer shelf site also exhibited an H' value of 4.1 (Table 9.1). The lowest diversity occurred at station 8047, a shallow inner shelf station located near the mouth of San Diego Bay (Table 9.1). Evenness (J') compliments diversity, with higher J' values (on a scale of 0–1) indicating that species are more evenly distributed and that an assemblage is not dominated by a few highly abundant species. During 2010, J' values across all strata ranged between 0.58–0.95 (Table 9.1), with evenness tending to increase with depth (Figure 9.2D). Thus, inner shelf regions possessed the lowest average evenness values while upper slope sites possessed the greatest evenness values.

Dominance

Swartz dominance values across the three shelf strata ranged between 4–55 taxa per station during 2010, while values at upper slope sites ranged between 7–30 (Table 9.1). Average dominance was notably higher (i.e., lower index values) at inner shelf and upper slope sites than at mid- and outer slope sites (Figure 9.2E). As expected, dominance values followed patterns similar to diversity values. For example, the three sites with the lowest dominance (stations 8001, 8003, 8024; index values≥45) also exhibited high H' values (≥4.2), while the few stations with dominance index values <10 (stations 8010, 8016, 8027, 8039, 8040, 8047) had relatively low H' values of 2.0 to 2.7 (Table 9.1).

Benthic response index (BRI)

The benthic response index (BRI) is a useful tool for evaluating environmental conditions in soft-bottom benthic habitats off southern California; however, it has only been calibrated for depths from 10 to 324 m (Smith et al. 2001). BRI values <25 are considered indicative of reference conditions, while values between 25–34 represent a minor or marginal deviation from reference conditions. High BRI values >34 represent progressive levels of impact, including losses in biodiversity or community function, and ultimately defaunation. In 2010, regional BRI values ranged from 2–28 (Table 9.1), with three stations (8032, 8033 located immediately north of the South Bay Ocean Outfall, 8037 located offshore of the Point Loma Ocean Outfall) possessing BRI values ≥25 and indicating a slight deviation from reference conditions. Average BRI values varied by depth strata, with inner, mid-, and outer shelf sites possessing average BRI values of 17, 12, and 13, respectively (Figure 9.2F). BRI values

Table 9.1

Macrofaunal community parameters calculated per 0.1-m^2 grab at regional stations sampled during 2010. SR = species richness; Abun = abundance; H' = Shannon diversity index; J' = evenness; Dom = Swartz dominance; BRI = benthic response index; *n* = 1.

	Station	Depth (m)	SR	Abun	H'	J'	Dom	BRI
Inner Shelf	8016	9	29	253	2.4	0.71	6	na
	8047	9	18	102	2.0	0.70	4	na
	8010	10	32	344	2.2	0.64	5	2
	8017	12	53	178	3.4	0.86	20	10
	8025	17	37	100	2.7	0.74	12	22
	8027	21	74	535	2.5	0.58	9	19
	8033	22	74	497	2.8	0.65	11	25
	8021	24	62	189	3.5	0.85	23	24
Mid-shelf	8023	31	174	808	3.8	0.74	41	19
	8032	33	140	811	3.6	0.74	26	26
	8013	36	157	645	4.2	0.83	40	24
	8034	38	52	241	2.8	0.71	13	12
	8003	40	131	460	4.4	0.90	49	19
	8001	50	105	335	4.2	0.91	45	13
	8009	52	115	430	4.1	0.86	39	14
	8029	52	34	86	3.1	0.89	15	12
	8007	58	87	414	3.8	0.85	28	10
	8005	62	117	444	4.0	0.85	40	13
	8011	78	65	225	3.1	0.74	23	2
	8028	80	89	280	3.4	0.76	27	5
	8019	81	62	167	3.2	0.79	24	5
	8006	84	71	238	3.4	0.79	24	3
	8022	85	79	308	3.1	0.71	19	5
	8002	94	73	377	3.2	0.75	19	9
	8020	96	98	350	3.9	0.85	31	8
	8024	101	129	348	4.5	0.92	55	13
	8014	112	84	298	4.0	0.91	34	14
Outer Shelf	8012	123	99	345	4.1	0.89	36	11
	8008	125	94	371	3.7	0.82	27	15
	8026	155	43	208	3.1	0.82	12	4
	8018	161	37	85	3.0	0.83	16	12
	8015	167	52	152	3.5	0.89	23	17
	8004	196	65	215	3.8	0.90	27	21
Upper Slope	8030	203	71	227	3.9	0.91	30	14
	8045	212	44	100	3.5	0.91	20	17
	8043	222	49	101	3.7	0.95	25	16
	8038	263	48	110	3.5	0.90	21	12
	8037	317	28	76	2.7	0.81	11	28
	8040	421	28	114	2.6	0.77	7	na
	8039	433	28	91	2.7	0.81	9	na

na = not applicable

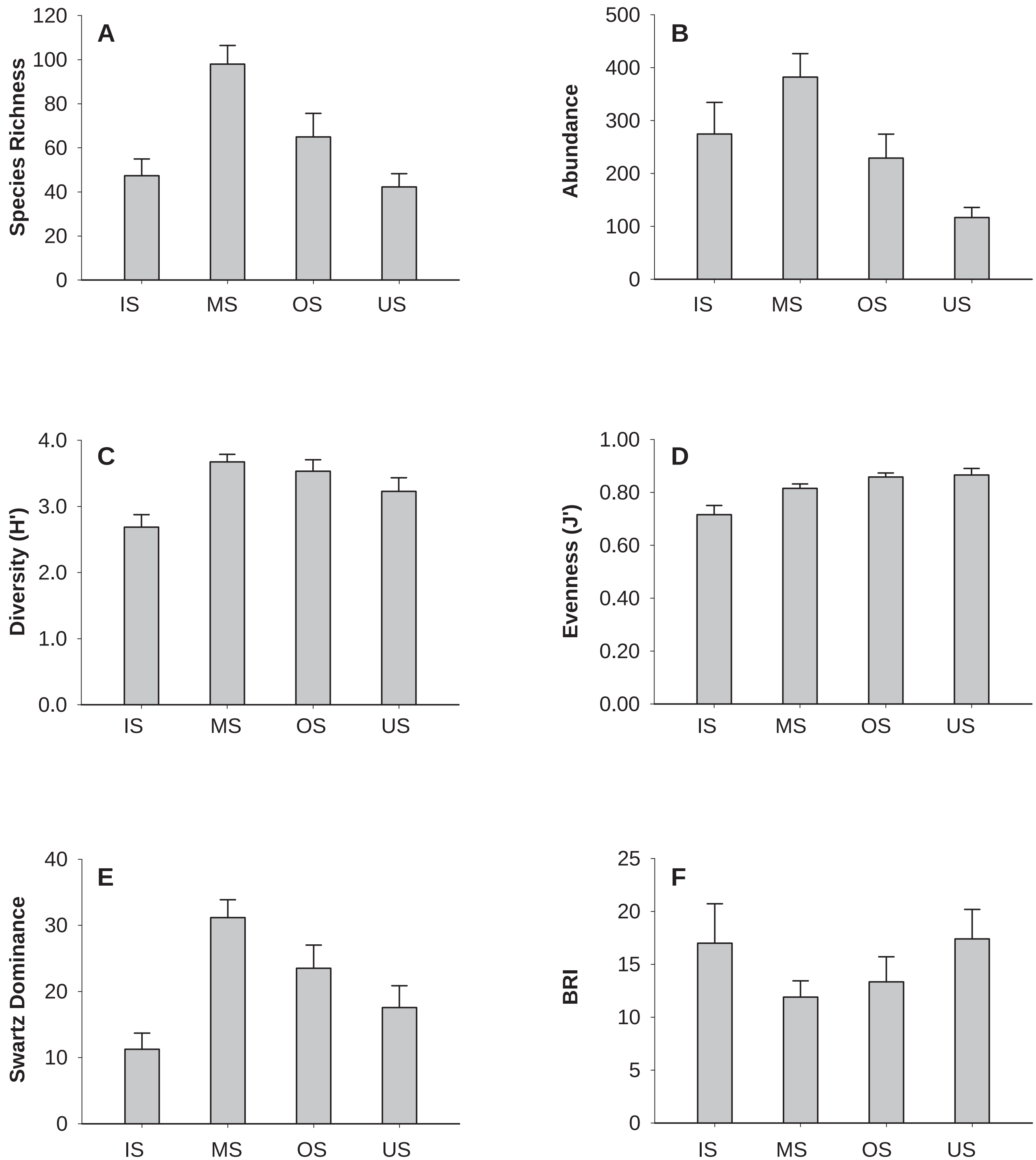

Figure 9.2

Comparison of macrofaunal community structure metrics for the four major depth strata sampled at the regional stations during 2010. Data are expressed for each depth stratum as means + one standard error (per 0.1 m^2). IS = inner shelf (5–30 m; *n* = 8); MS = mid-shelf (30–120 m; *n* = 19); OS = outer shelf (120–200 m; *n* =6); US = upper slope (200–500 m; *n* = 7).

were not calculated for the two shallowest inner shelf stations (< 10 m depth) and the two deepest upper slope stations (> 324 m depth) because calibration of the index for depths encountered at those locations has never occurred. Overall, 92% of the sites where BRI was calculated were similar to reference conditions while the remaining 8% showed only marginal deviation from reference conditions.

Dominant Taxa

As in previous years, 2010 macrofaunal communities in the San Diego region were dominated by polychaete worms (Table 9.2) in terms of diversity, where they accounted for 54% of all species collected. Arthropods (mostly crustaceans, but also including pycnogonids) and molluscs were the next two most diverse taxa, accounting for 19% and 13% of species, respectively. Echinoderms accounted for 6% of all taxa, while all other phyla combined (e.g., Chordata, Cnidaria, Nematoda, Nemertea, Phoronida, Platyhelminthes, Sipuncula) accounted for the remaining 8%. Patterns apparent in the proportions of major taxa across shelf strata include: (1) the contribution of polychaetes to overall macroinvertebrate diversity increased from 42% along the inner shelf, to 55% along the mid-shelf, to 65% along the outer shelf, (2) the percentage of echinoderms increased slightly as depth increased, and (3) the proportions of crustaceans and the other phyla typically decreased with depth (Figure 9.3A). The greatest difference in invertebrate assemblages occurred between the continental shelf and upper slope when the percentage of molluscs increased sharply and the proportion of polychaetes decreased. The proportion of echinoderms remained about the same between upper slope and outer shelf sites.

Polychaetes were also the most numerous invertebrates collected, accounting for 59% of the total abundance (Table 9.2). Crustaceans accounted for 14% of the animals, molluscs 12%, echinoderms 10%, and the remaining phyla 5%. Abundance patterns varied among strata (Figure 9.3B) with the proportion of polychaetes being lower at inner and mid-shelf stations (i.e., ~54% each) than along either the outer shelf or upper slope (i.e., 74% and 62%, respectively). The lower proportional abundance of polychaetes along mid- and inner shelf sites corresponded to considerably higher numbers of ophiuroids (i.e., 18%) and crustaceans (i.e., 23%) at these depths, respectively.

Table 9.2
The percent composition of species and abundance by phyla for regional stations sampled during 2010. Data are expressed as means (range) for all stations combined; $n = 40$.

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	54 (14–79)	59 (4–86)
Arthropoda (Crustacea)	19 (0–62)	14 (0–76)
Mollusca	13 (1–43)	12 (1–38)
Echinodermata	6 (0–14)	10 (0–42)
Other Phyla	8 (0–19)	5 (0–32)

As expected, dominant species encountered varied across strata (Table 9.3). For example, the 10 most abundant species along the inner shelf included six polychaetes, three amphipod crustaceans, and one anthozoan. Of these, the spionid polychaete *Spiophanes norrisi* was clearly dominant averaging about 62 individuals per 0.1-m^2 grab. All other species averaged < 24 animals/grab. Additionally, *S. norrisi* was the most widely distributed of the common inner shelf species, occurring at all eight sites surveyed. In contrast, the oweniid polychaete *Owenia collaris* exhibited a more restricted distribution, occurring at only one site. The top 10 dominant species along the mid-shelf included one ophiuroid, eight polychaetes, and one bivalve. Of these, the brittle star *Amphiodia urtica* was the most common species, averaging about 41 animals per grab and occurring at 74% of the sites. *Spiophanes norrisi* was the next most abundant species, and averaged about 32 animals per grab. All other species averaged < 11 animals/grab. The top 10

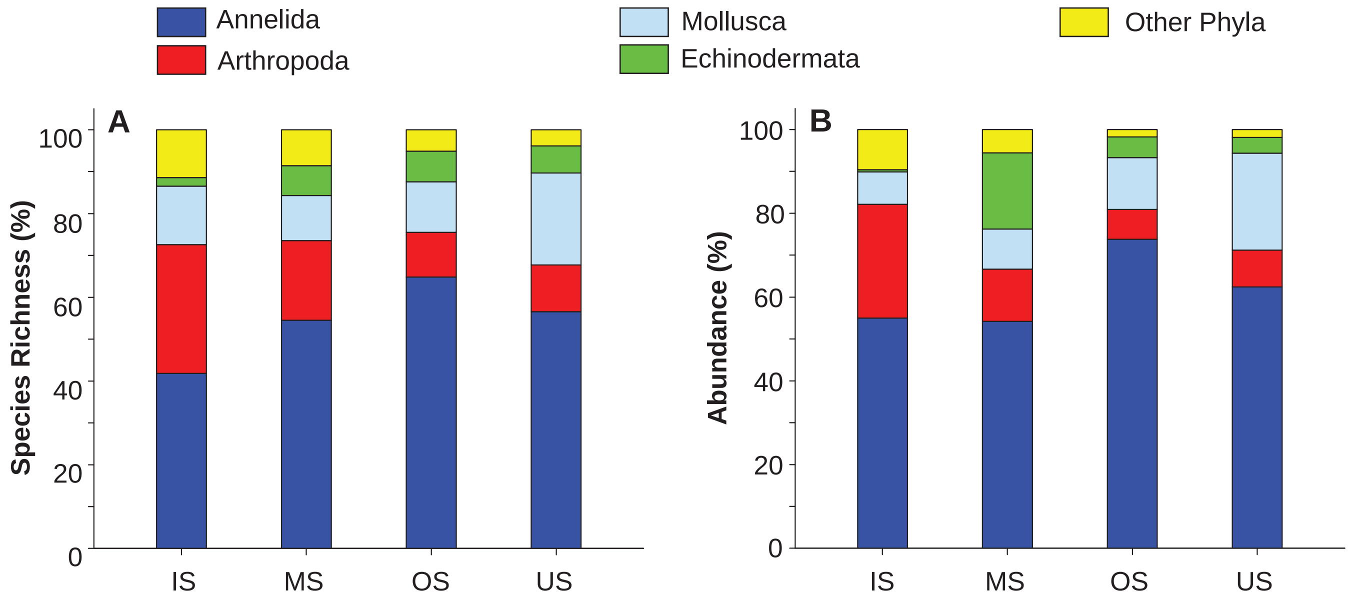

Figure 9.3
Comparison of percent composition of species and abundance by major phylum for each depth stratum sampled at the regional stations during 2010. IS = inner shelf (5–30 m; *n* = 8); MS = mid-shelf (30–120 m; *n* = 19); OS = outer shelf (120–200 m; *n* =6); US = upper slope (200–500 m; *n* = 7).

species recorded along the outer shelf included eight polychaetes and two bivalves. Of these, the cirratulid polychaete *Aphelochaeta glandaria* was most abundant, averaging 24 animals per grab, while none of the other dominant outer shelf species exceeded mean densities of 10 animals per grab. The 10 most abundant species along the upper slope included seven polychaetes and three bivalves. The maldanid polychaete *Maldane sarsi* was the most abundant upper slope species with an average of 11 animals/grab, while the second most abundant species was the bivalve *Yoldiella nana*, which averaged 5 animals/grab.

Classification of Macrobenthic Assemblages

Classification (cluster) and ordination analyses were used to discriminate between the major macrobenthic assemblages that occurred at the regional stations sampled off San Diego. Seven main habitat-related assemblages were identified in 2010 based on results of these cluster analyses (Figure 9.4A, Table 9.4). These assemblages, referred to herein as cluster groups A–G, varied in terms of the specific taxa (mostly species) present and the relative abundance of each taxon, and encompassed sites from varying depth regimes and/or sediment microhabitats (Figures 9.4B, 9.5). The SIMPROF procedure indicated statistically significant non-random structure among samples ($\pi = 7.42$, $p < 0.001$), and an nMDS ordination supported the validity of the cluster groups (Figure 9.4C). SIMPER analysis identified species that were characteristic, though not always the most abundant, within assemblages; a comparison of the most abundant taxa for each cluster group combined with SIMPER results is indicated in Table 9.4. A list of species identified by SIMPER as discriminating between individual cluster groups is presented in Appendix H.1. Overall, clusters were very similar and no single species strongly discriminated between groups. On average, 121 species contributed to 75% of the dissimilarity between any two cluster groups.

Cluster group A represents inner shelf assemblages that occurred at four stations sampled in relatively shallow waters (9–12 m) near the mouths of Mission Bay and San Diego Bay. Sites within this cluster were characterized by an average of 33 taxa and 219 individuals per 0.1 m^2 grab. Overall, the most abundant species were the megaluropid amphipod *Gibberosus myersi* with ~24 animals/grab and unidentified anthozoans (Actiniaria) with ~21 animals/grab. Although only recorded at one

Table 9.3

The 10 most abundant macroinvertebrates collected at regional benthic stations sampled during 2010. AS = abundance/survey; PO = percent occurrence (percent of total annual samples for which the species was collected); AO = abundance/occurrence. Abundance values are expressed as mean number of individuals per 0.1-m^2 grab sample.

Strata	Species	Higher Taxa	AS	PO	AO
Inner Shelf	*Spiophanes norrisi*	Annelida: Spionidae	62.1	100.0	62.1
	Apoprionospio pygmaea	Annelida: Spionidae	23.4	87.6	27.0
	Owenia collaris	Annelida: Oweniidae	18.3	12.6	146.0
	Gibberosus myersi	Arthropoda: Amphipoda	12.3	50.0	24.9
	Spiophanes duplex	Annelida: Spionidae	12.0	37.5	32.1
	Actiniaria	Cnidaria: Anthozoa	10.8	50.0	21.6
	Monticellina siblina	Annelida: Cirratulidae	6.3	50.0	12.9
	Metharpinia jonesi	Arthropoda: Amphipoda	6.0	50.0	11.7
	Mediomastus sp	Annelida: Capitellidae	5.4	62.4	8.7
	Rhepoxynius menziesi	Arthropoda: Amphipoda	5.4	50.0	10.8
Mid-shelf	*Amphiodia urtica*	Echinodermata: Ophiuroidea	40.5	73.8	55.2
	Spiophanes norrisi	Annelida: Spionidae	32.4	47.4	68.4
	Axinopsida serricata	Mollusca: Bivalvia	10.5	57.9	18.3
	Mediomastus sp	Annelida: Capitellidae	6.0	89.4	6.9
	Polycirrus sp A	Annelida: Terebellidae	5.4	78.9	6.9
	Euclymeninae sp A	Annelida: Maldanidae	5.1	68.4	7.5
	Spiophanes berkeleyorum	Annelida: Spionidae	4.8	68.4	7.2
	Aricidea (*Acmira*) *catherinae*	Annelida: Paraonidae	4.8	52.5	9.0
	Sternaspis fossor	Annelida: Sternaspidae	4.2	73.8	5.4
	Monticellina cryptica	Annelida: Cirratulidae	4.2	68.4	6.0
Outer Shelf	*Aphelochaeta glandaria* Cmplx	Annelida: Cirratulidae	23.7	100.0	23.7
	Monticellina siblina	Annelida: Cirratulidae	9.6	66.6	14.4
	Chaetozone sp SD5	Annelida: Cirratulidae	9.6	50.0	18.9
	Spiophanes kimballi	Annelida: Spionidae	6.9	83.4	8.1
	Mediomastus sp	Annelida: Capitellidae	6.6	100.0	6.6
	Tellina carpenteri	Mollusca: Bivalvia	5.4	100.0	5.4
	Aricidea (*Acmira*) *catherinae*	Annelida: Paraonidae	5.4	83.4	6.3
	Polycirrus sp A	Annelida: Terebellidae	5.4	50.0	10.8
	Axinopsida serricata	Mollusca: Bivalvia	5.1	83.4	6.0
	Chaetozone hartmanae	Annelida: Cirratulidae	4.2	50.0	8.7
Upper Slope	*Maldane sarsi*	Annelida: Maldanidae	10.5	85.8	12.3
	Yoldiella nana	Mollusca: Bivalvia	4.5	28.5	15.6
	Eclysippe trilobata	Annelida: Ampharetidae	4.2	28.5	14.4
	Spiophanes kimballi	Annelida: Spionidae	3.9	57.0	6.9
	Tellina carpenteri	Mollusca: Bivalvia	3.6	57.0	6.3
	Mediomastus sp	Annelida: Capitellidae	3.6	42.9	8.7
	Myriochele gracilis	Annelida: Oweniidae	3.3	57.0	5.7
	Ampharete finmarchica	Annelida: Ampharetidae	3.0	57.0	5.4
	Macoma carlottensis	Mollusca: Bivalvia	2.7	42.9	6.0
	Paraprionospio alata	Annelida: Spionidae	2.4	85.8	2.7

site in this cluster, the oweniid polychaete *Owenia collaris* (146 individuals at station 8010) is also historically characteristic for shallow, inner shelf regions off San Diego. SIMPER analysis revealed the two most characteristic animals for this cluster to be *G. myersi* and the phoxocephalid amphipod *Metharpinia jonesi*. Sediments at these sites were composed almost entirely of sand and shell hash with only 1% fines, and with a total organic carbon (TOC) content of 0.1% by weight (% wt).

Cluster group B represents assemblages from the two deepest sites sampled along the upper slope at depths of 421 and 433 m. These assemblages averaged 28 taxa and 103 individuals per grab, the lowest values among all seven cluster groups. Polychaetes and molluscs were numerically dominant, with the three most abundant species being the maldanid polychaete *Maldane sarsi* with ~20 animals/grab, the bivalve *Yoldiella nana* with ~16 animals/grab, and the ampharetid polychaete *Eclysippe trilobata* with ~15 animals/grab. SIMPER analysis revealed these three species to also be most characteristic of the group. Sediments at these two sites were finer (i.e., 71% fines) than those occurring in the other cluster groups (i.e., 0–64% fines), and had an average TOC value of 1.9% wt.

Cluster group C represents mid-shelf assemblages that occurred at depths of 38 and 52 m. Species richness within these assemblages averaged 43 taxa, while abundance averaged 164 individuals per 0.1 m^2. Polychaetes and crustaceans were numerically dominant, with the three most abundant species being the spionid polychaetes *Spiophanes norrisi* (~45 animals/grab) and *Spio maculata* (~19 animals/grab), and the terebellid polychaete *Lanassa venusta venusta* (7 animals/grab). SIMPER found *S. norrisi* to characterize the assemblages in this clade, along with the cirolanid isopod *Eurydice caudata* and the terebellid polychaete *Polycirrus* sp A. Sediments at these sites were composed entirely of sand and other coarse particles (i.e., 0% fines), including black sand and red relict sand, with no measurable TOC present.

Cluster group D is a sister group to cluster C (Figure 9.4A), and represents inner shelf to shallow mid-shelf assemblages that occurred at depths ranging from 17 to 40 m. These assemblages were typical of relatively shallow-water sites in the region with an average of 106 taxa and 506 individuals per 0.1 m^2. The dominant species at these sites included the spionids *Spiophanes norrisi* (~120 animals/grab), *Apoprionospio pygmaea* (~19 animals/grab), and *Spiophanes duplex* (~17 animals/grab). Characteristic species included *S. norrisi*, *S. duplex*, and the capitellid polychaete *Mediomastus* sp. Sediment composition at the sites within this group averaged 10% fines and 1.0% wt TOC.

Cluster group E represents outer shelf assemblages at depths of 125–161 m, including two sites along the Coronado Bank. These assemblages averaged 58 taxa and 221 individuals per 0.1 m^2. Dominant species included the cirratulid polychaetes *Aphelochaeta glandaria* with ~40 animals/grab, *Chaetozone* sp SD5 with 19 animals/grab, and *Monticellina siblina* with ~17 animals/grab. These species were also identified as most characteristic of the group based on SIMPER results. Sediments at these sites were relatively coarse containing gravel, rock, shell hash and only 22% fines. TOC content at these sites averaged 2.5% wt, which was the highest among the seven cluster groups (Figure 9.5).

Cluster group F contains five upper slope and two outer shelf sites that ranged in depth from 167–317 m (Figure 9.4A). These assemblages averaged 51 taxa and 140 individuals per 0.1 m^2. Dominant species included the spionid *Spiophanes kimballi* with ~9 animals/grab, *Mediomastus* sp with ~6 animals/grab, and *Maldane sarsi* with ~5 animals/grab, and the bivalve *Tellina carpenteri* with ~6 animals/grab. SIMPER revealed *S. kimballi* and *T. carpenteri* to characterize the group. The percentage of fines was the second highest for all cluster groups, averaging 64%. TOC averaged 1.7% wt.

Cluster group G is a sister group to cluster F (Figure 9.4A), and contains the majority of mid- and outer shelf sites at depths from 50–123 m. This group possessed the second highest average species richness (91 species) and averaged 326 individuals

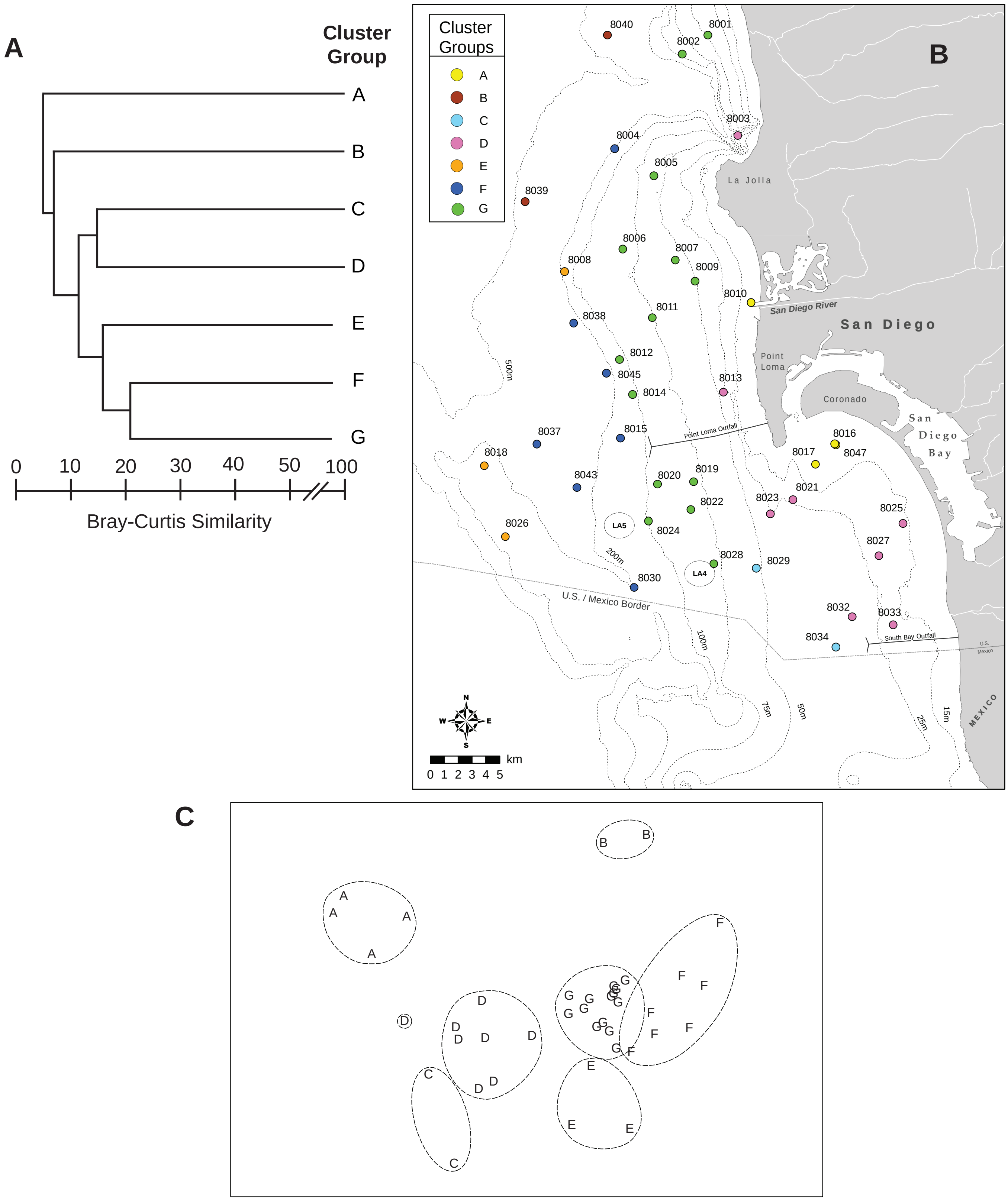

Figure 9.4

Results of multivariate analyses of macrofaunal abundance data for the regional benthic statons sampled during 2010. Data are presented as: (A) cluster results; (B) spatial distribution of sediment samples as delineated by cluster analysis; (C) nMDS ordination illustrating distribution of samples in multivariate space. nMDS plot stress = 0.15. Dashed ellipses enclose station groups within a similarity of 21%.

Table 9.4

Description of cluster groups A–G defined in Figure 9.4. Data for percent fines, total organic carbon (TOC; % weight), depth (m), species richness, and infaunal abundance, are expressed as mean values per 0.1-m^2 grab over all stations in each group. Bold values indicate taxa that were considered most characteristic of that group according to SIMPER analysis (i.e., greatest percentage contribution to within-group similarity)

	Group A	Group B	Group C	Group D	Group E	Group F	Group G
n	4	2	2	8	3	7	14
Percent Fines	1	71	0	10	22	64	41
Depth	10	427	45	28	147	226	83
TOC	0.1	1.9	0.0	1.0	2.5	1.7	0.6
Species Richness	33	28	43	106	58	51	91
Abundance	219	103	164	506	221	140	326
Taxa				**Mean Abundance**			
Owenia collaris	36.5						0.1
Gibberosus myersi	**23.5**		1.0	0.6			
Actiniaria	21.3	0.5		0.6			0.1
Spiophanes norrisi	12.8	1.0	**44.5**	**120.4**			0.6
Metharpinia jonesi	**11.8**						
Maldane sarsi		**20.0**				4.9	1.4
Yoldiella nana		**15.5**					
Eclysippe trilobata		**14.5**			1.3		0.5
Myriochele gracilis		10.0				0.7	1.0
Phoronis sp		4.0		0.5			0.3
Spio maculata			18.5				
Lanassa venusta venusta			7.0	0.1		0.6	0.4
Eurydice caudata			**6.5**	0.6			0.4
Mooreonuphis sp SD1			5.0				
Apoprionospio pygmaea	10.3			18.6			0.1
Spiophanes duplex				**16.6**	0.3	0.3	2.9
Mediomastus sp	0.5		0.5	**12.8**	6.0	5.7	4.4
Monticellina siblina			0.5	10.9	**17.3**		1.8
Aphelochaeta glandaria Cmplx				0.4	**40.3**	2.7	1.6
Chaetozone sp SD5			1.0	7.8	**19.0**	0.1	0.1
Mooreonuphis sp			2.0		6.7		0.1
Huxleyia munita					6.7		
Spiophanes kimballi					2.0	**8.6**	0.9
Tellina carpenteri					4.0	**6.4**	0.7
Macoma carlottensis						3.6	0.1
Amphiodia urtica			0.5	0.8		1.0	**55.6**
Axinopsida serricata					4.7	2.7	14.5
Polycirrus sp A			**2.0**	1.6	1.0	1.7	8.4
Sternaspis fossor				0.5	0.3	0.9	**5.6**
Prionospio (*Prionospio*) *dubia*				0.3	1.7	0.3	**5.4**

per 0.1 m^2. Dominant species included the ophiuroid *Amphiodia urtica* (~56 animals/grab), the bivalve *Axinopsida serricata* (~15 animals/grab), and the terebellid Polycirrus sp A (~8 animals/grab). SIMPER identified *A. urtica*, the sternaspid polychaete *Sternaspis fossor* and the spionid *Prionospio* (*Prionospio*) *dubia* to be characteristic of the clade. Sediments associated with this cluster were mixed, averaging 41% fines, and with an average TOC concentration of 1.7% wt.

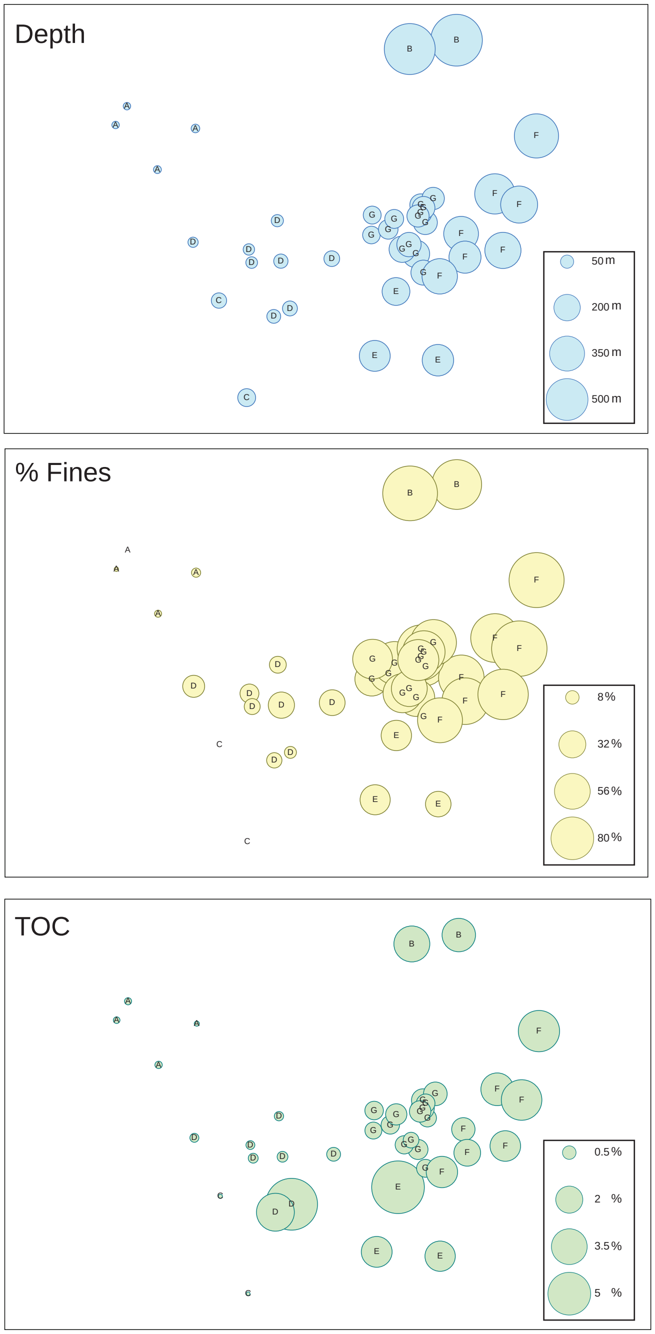

Figure 9.5

Ordination (nMDS) of macrofaunal abundance data for 2010 regional stations (see Figure 9.4), with superimposed circles representing station depth, and the amount of fine particles (% fines) and total organic carbon (TOC, % wt) in sediments. Circles vary in size according to the magnitude of each value. Stress = 0.15.

Discussion

The SCB benthos has long been considered to be composed of "patchy" habitats, with the distribution of species and communities exhibiting considerable spatial variability. Results of regional surveys off San Diego support this characterization. Benthic assemblages surveyed during 2010 segregated by habitat characteristics such as depth and sediment grain size, and were similar to macrofaunal assemblages observed during previous regional surveys. Two distinct, relatively shallow nearshore macrofaunal assemblages occurred off San Diego and were similar to those found in shallow, sandy sediment habitats across the SCB (Barnard 1963, Jones 1969, Thompson et al. 1987, 1992, ES Engineering Science 1988, Mikel et al. 2007). These assemblages (cluster groups A and D) occurred at inner to mid-shelf sites (9–40 m) that were characterized by coarse sediments averaging between 1–10% fines. Typically, polychaetes such as *Owenia collaris* and *Spiophanes norrisi* are numerically dominant in these types of assemblages.

The largest number of sites sampled off San Diego in 2010 occurred in mid- to outer shelf areas (50–123 m depths), and were characterized by typical mixed sediment (i.e., 41% fines) macrofaunal assemblages dominated by the ophiuroid *Amphiodia urtica*. These cluster group G assemblages correspond to the *Amphiodia* "mega-community" described by Barnard and Ziesenhenne (1961), and are common in the Point Loma region off San Diego as well as other parts of the southern California mainland shelf (Jones 1969, Fauchald and Jones 1979, Thompson et al. 1987, 1993, Zmarzly et al. 1994, Diener and Fuller 1995, Bergen et al. 1998, 2000, 2001, Mikel et al. 2007, City of San Diego 2010a, 2011). Outer shelf stations at depths of 125–161 m with coarser sediments of ~22% fines (including sites along the Coronado Bank) were typically devoid of *A. urtica*, and were instead dominated by polychaete worms (especially the cirratulids *Aphelochaeta glandaria*, *Monticellina siblina* and *Chaetozone* sp SD5; i.e., cluster group E).

Similar to patterns observed in past years, upper slope habitats off San Diego were characterized by a high percentage of fine sediments with associated macrofaunal assemblages that were distinct from most shelf stations surveyed. Macrofaunal assemblages from five upper slope stations at depths <320 m clustered together with those from the two deepest outer shelf stations, and lacked the high abundances of *A. urtica* characteristic of most other outer and mid-shelf locations. Polychaetes, particularly *Spiophanes kimballi*, *Mediomastus* sp and *Maldane sarsi* were numerically dominant. In contrast, assemblages from the two deepest upper slope stations at 421−433 m clustered together in their own clade (cluster group B), and resided in the finest sediments of all sites surveyed. The characteristic species in this latter group included polychaetes and molluscs such as the maldanid *Maldane sarsi* and the bivalve *Yoldiella nana*.

Although benthic communities off San Diego vary across depth and sediment gradients, there was no evidence of disturbance during the 2010 regional survey that could be attributed to wastewater discharges, disposal sites or other point sources. Benthic macrofauna appear to be in good condition throughout the region, with 92% of the sites surveyed in 2010 being in reference condition based on assessments using the BRI. This is not unexpected as Ranasinghe et al. (2010) recently reported that 98% of the entire SCB was in good condition based on assessment data gathered during the 1994−2003 bight-wide surveys.

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Glossary

GLOSSARY

Absorption
The movement of dissolved substances (e.g., pollution) into cells by diffusion.

Adsorption
The adhesion of dissolved substances to the surface of sediment or on the surface of an organism (e.g., a flatfish).

Anthropogenic
Made and introduced into the environment by humans, especially pertaining to pollutants.

Assemblage
An association of interacting populations in a given habitat (e.g., an assemblage of benthic invertebrates on the ocean floor).

BACIP Analysis
An analytical tool used to assess environmental changes caused by the effects of pollution. A statistical test is applied to data from matching pairs of control and impacted sites before and after an event (i.e., initiation of wastewater discharge) to test for significant change. Significant differences are generally interpreted as being the result of the environmental change attributed to the event. Variation that is not significant reflects natural variation.

Benthic
Pertaining to the environment inhabited by organisms living on or in the ocean bottom.

Benthos
Living organisms (e.g., algae and animals) associated with the sea bottom.

Bioaccumulation
The process by which a chemical becomes accumulated in tissue over time through direct intake of contaminated water, the consumption of contaminated prey, or absorption through the skin or gills.

Biota
The living organisms within a habitat or region.

BOD
Biochemical oxygen demand (BOD) is the amount of oxygen consumed (through biological or chemical processes) during the decomposition of organic material contained in a water or sediment sample. It is a measure for certain types of organic pollution, such that high BOD levels suggest elevated levels of organic pollution.

BRI
The benthic response index (BRI) measures levels of environmental disturbance by assessing the condition of a benthic assemblage. The index was based on organisms found in the soft sediments of the Southern California Bight (SCB).

CFU
The colony-forming unit (CFU) is the bacterial cell or group of cells which reproduce on a plate and result in a visible colony that can be quantified as a measurement of density; it is often used to estimate bacteria concentrations in ocean water.

Control site
A geographic location that is far enough from a known pollution source (e.g., ocean outfall) to be considered representative of an undisturbed environment. Data collected from control sites are used as a reference and compared to impacted sites.

COP
The California Ocean Plan (COP) is California's ocean water quality control plan. It limits wastewater discharge and implements ocean monitoring. Federal law requires the plan to be reviewed every three years.

Crustacea
A group (subphylum) of marine invertebrates characterized by jointed legs and an exoskeleton (e.g., crabs, shrimp, and lobster).

CTD
A device consisting of a group of sensors that continually measure various physical and chemical properties such as conductivity (a proxy for salinity), temperature, and pressure (a proxy for depth) as it

is lowered through the water. These parameters are used to assess the physical ocean environment.

Demersal
Organisms living on or near the bottom of the ocean and capable of active swimming.

Dendrogram
A tree-like diagram used to represent hierarchal relationships from a multivariate analysis where results from several monitoring parameters are compared among sites.

Detritus
Particles of organic material from decomposing organisms. Used as an important source of nutrients in a food web.

Diversity
A measurement of community structure which describes the abundances of different species within a community, taking into account their relative rarity or commonness.

Dominance
A measurement of community structure that describes the minimum number of species accounting for 75% of the abundance in each grab.

Echinodermata
A group (phylum) of marine invertebrates characterized by the presence of spines, a radially symmetrical body, and tube feet (e.g., sea stars, sea urchins, and sea cucumbers).

Effluent
Wastewater that flows out of a sewer, treatment plant outfall, or other point source and is discharged into a water body (e.g. ocean, river).

FIB
Fecal indicator bacteria (FIB) are the bacteria (total coliform, fecal coliform, and enterococcus) measured and evaluated to provide information about the movement and dispersion of wastewater discharged to the Pacific Ocean through the outfall.

Halocline
A vertical zone of water in which the salinity changes rapidly with depth.

Impact site
A geographic location that has been altered by the effects of a pollution source, such as a wastewater outfall.

Indicator species
Marine invertebrates whose presence in the community reflects the health of the environment. The loss of pollution-sensitive species or the introduction of pollution-tolerant species can indicate anthropogenic impact.

Infauna
Animals living in the soft bottom sediments usually burrowing or building tubes within.

Invertebrate
An animal without a backbone (e.g., sea star, crab, and worm).

Kurtosis
A measure that describes the shape (i.e., peakedness or flatness) of distribution relative to a normal distribution (bell shape) curve. Kurtosis can indicate the range of a data set, and is used herein to describe the distribution of particle sizes within sediment samples.

Macrobenthic invertebrate
Epifaunal or infaunal benthic invertebrates that are visible with the naked eye. This group typically includes those animals larger than meiofauna and smaller than megafauna. These animals are collected in grab samples from soft-bottom marine habitats and retained on a 1-mm mesh screen.

MDL
The EPA defines MDL (method detection limit) as “the minimum concentration that can be determined with 99% confidence that the true concentration is greater than zero.”

Megabenthic invertebrate
A larger, usually epibenthic and motile, bottom-dwelling animal such as a sea urchin, crab, or snail. These animals are typically collected by otter trawl nets with a minimum mesh size of 1 cm.

Mollusca
A taxonomic group (phylum) of invertebrates characterized as having a muscular foot, visceral mass, and a shell. Examples include snails, clams, and octupuses.

Motile
Self-propelled or actively moving.

Niskin bottle
A long plastic tube allowing seawater to pass through until the caps at both ends are triggered to close from the surface. They often are arrayed with several others in a rosette sampler to collect water at various depths.

Non-point source
Pollution sources from numerous points, not a specific outlet, generally carried into the ocean by storm water runoff.

NPDES
The National Pollutant Discharge Elimination System (NPDES) is a federal permit program that controls water pollution by regulating point sources that discharge pollutants into waters of the United States.

Ophiuroidea
A taxonomic group (class) of echinoderms that comprises the brittle stars. Brittle stars usually have five long, flexible arms and a central disk-shaped body.

PAHs
The USGS defines polycyclic aromatic hydrocarbons (PAHs) as, "hydrocarbon compounds with multiple benzene rings. PAHs are typical components of asphalts, fuels, oils, and greases."

PCBs
The EPA defines polychlorinated biphenyls (PCBs) as, "a category, or family, of chemical compounds formed by the addition of chlorine (C_{l2}) to biphenyl ($C_{12}H_{10}$), which is a dual-ring structure comprising two 6-carbon benzene rings linked by a single carbon-carbon bond."

PCB Congeners
The EPA defines a PCB congener as, "one of the 209 different PCB compounds. A congener may have between one and 10 chlorine atoms, which may be located at various positions on the PCB molecule."

Phi
The conventional unit of sediment size based on the log of sediment grain diameter. The larger the phi number, the smaller the grain size.

Plankton
Animal and plant-like organisms, usually microscopic, that are passively carried by ocean currents.

PLOO
The Point Loma Ocean Outfall (PLOO) is the underwater pipe originating at the Point Loma Wastewater Treatment Plant and used to discharge treated wastewater. It extends 7.2 km (4.5 miles) offshore and discharges into 96 m (320 ft) of water.

Point source
Pollution discharged from a single source (e.g., municipal wastewater treatment plant, storm drain) to a specific location through a pipe or outfall.

Polychaeta
A taxonomic group (class) of invertebrates characterized as having worm-like features, segments, and bristles or tiny hairs. Examples include bristle worms and tube worms.

Pycnocline
A depth zone in the ocean where sea water density changes rapidly with depth and typically is associated with a decline in temperature and increase in salinity.

Recruitment
The retention of young individuals into the adult population in an open ocean environment.

Relict sand
Coarse reddish-brown sand that is a remnant of a pre-existing formation after other parts have disappeared. Typically originating from land and transported to the ocean bottom through erosional processes.

Rosette sampler
A device consisting of a round metal frame housing a CTD in the center and multiple bottles (see Niskin bottle) arrayed about the perimeter. As the instrument is lowered through the water column, continuous measurements of various physical and chemical parameters are recorded by the CTD. Discrete water samples are captured at desired depths by the bottles.

SBOO
The South Bay Ocean Outfall (SBOO) is the underwater pipe originating at the International Wastewater Treatment Plant and used to discharge treated wastewater. It extends 5.6 km (3.5 miles) offshore and discharges into about 27 m (90 ft) of water.

SBWRP
The South Bay Water Reclamation Plant (SBWRP) provides local wastewater treatment services and reclaimed water to the South Bay. The plant began operation in 2002 and has a wastewater treatment capacity of 15 million gallons a day.

SCB
The Southern California Bight (SCB) is the geographic region that stretches from Point Conception, U.S.A. to Cabo Colnett, Mexico and encompasses nearly 80,000 km^2 of coastal land and sea.

Shell hash
Sediments composed of shell fragments.

Skewness
A measure of the lack of symmetry in a distribution or data set. Skewness can indicate where most of the data lies within a distribution. It can be used to describe the distribution of particle sizes within sediment grain size samples.

Sorting
The range of grain sizes that comprises marine sediments. Also refers to the process by which sediments of similar size are naturally segregated during transport and deposition according to the velocity and transporting medium. Well sorted sediments are of similar size (such as desert sand), while poorly sorted sediments have a wide range of grain sizes (as in a glacial till).

Species richness
The number of species per sample or unit area. A metric used to evaluate the health of macro-benthic communities.

Standard length
The measurement of a fish from the most forward tip of the body to the base of the tail (excluding the tail fin rays). Fin rays can sometimes be eroded by pollution or preservation so measurement that includes them (i.e., total length) is considered less reliable.

Thermocline
The zone in a thermally stratified body of water that separates warmer surface water from colder deep water. At a thermocline, temperature changes rapidly over a short depth.

Tissue burden
The total amount of measured chemicals that are present in the tissue (e.g. fish muscle).

Transmissivity
A measure of water clarity based upon the ability of water to transmit light along a straight path. Light that is scattered or absorbed by particulates (e.g., plankton, suspended solid materials) decreases the transmissivity (or clarity) of the water.

Upwelling
The movement of nutrient-rich and typically cold water from the depths of the ocean to the surface waters.

USGS
The United States Geological Survey (USGS) provides geologic, topographic, and hydrologic information on water, biological, energy, and mineral resources.

Van Dorn bottle

A water sampling device made of a plastic tube open at both ends that allows water to flow through. Rubber caps at the tube ends can be triggered to close underwater to collect water at a specified depth.

Van Veen grab

A mechanical device designed to collect ocean sediment samples. The device consists of a pair of hinged jaws and a release mechanism that allows the opened jaws to close and entrap a 0.1 m^2 sediment sample once the grab touches bottom.

Wastewater

A mixture of water and waste materials originating from homes, businesses, industries, and sewage treatment plants.

ZID

The zone of initial dilution (ZID) is the region of initial mixing of the surrounding receiving waters with wastewater from the diffuser ports of an outfall. This area includes the underlying seabed. In the ZID, the environment is chronically exposed to pollutants and often is the most impacted.

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Appendices

Appendix A

Supporting Data

2010 SBOO Stations

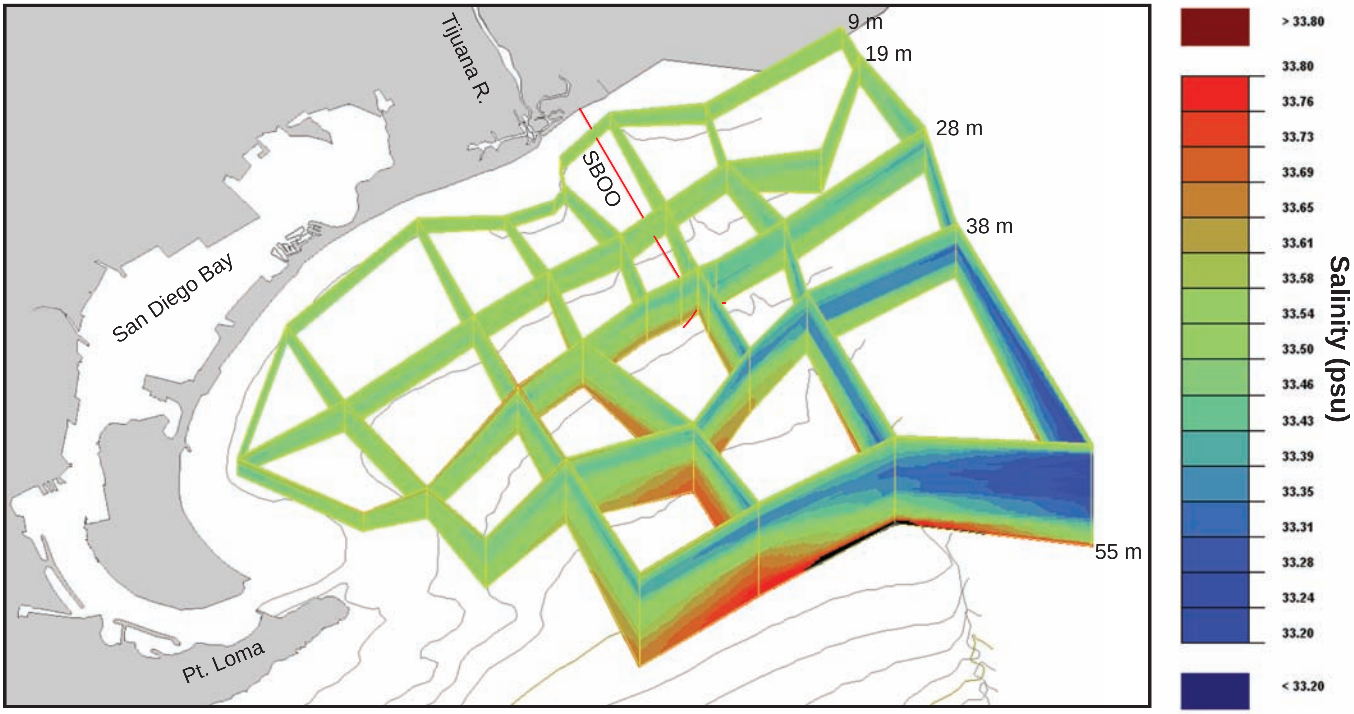
Oceanographic Conditions

Appendix A.1

Summary of the dates CTD casts were conducted during 2010. Stations were sampled monthly, usually over a 3-day period. This included 11 stations sampled on the day designated “North Water Quality” (stations I28–I38), 15 stations sampled on the day designated “Mid Water Quality” (stations I12, I14–I19, I22–I27, I39, I40), and 14 stations sampled on the day designated “South Water Quality” (stations I1–I11, I13, I20, I21).

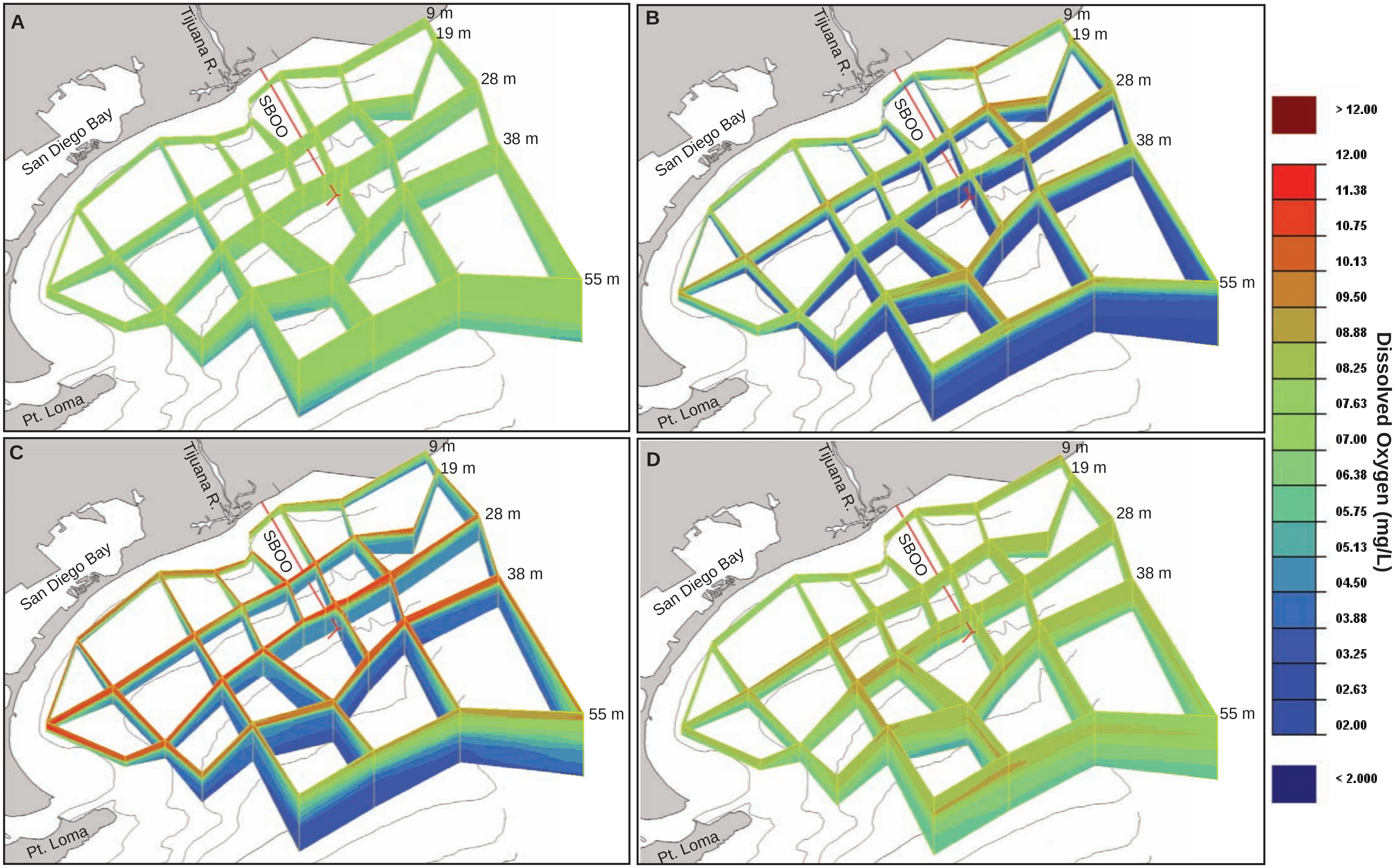
	2010 Sample Dates											
Sample Group	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
North Water Quality	7	26	6	ns	11	3	12	2	7	12	15	9
Mid Water Quality	5	23	15	ns	12	2	13	4	8	14	16	7
South Water Quality	6	25	17	ns	10	1	14	3	9	13	17	8

ns = not sampled (see text)



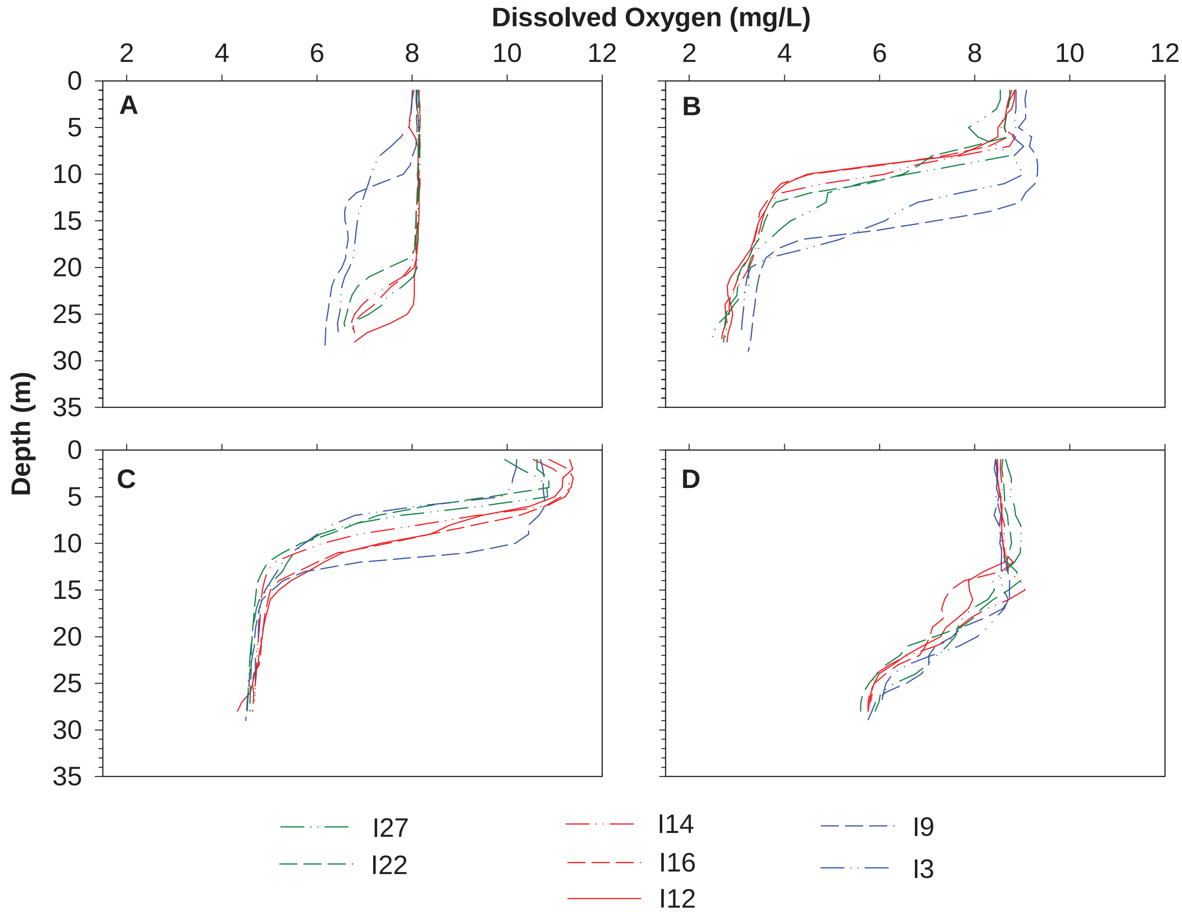
Appendix A.2

Levels of salinity recorded in 2010 for the SBOO region during July. Data were collected over three days; see Appendix A.1 for specific sample dates and stations sampled each day.



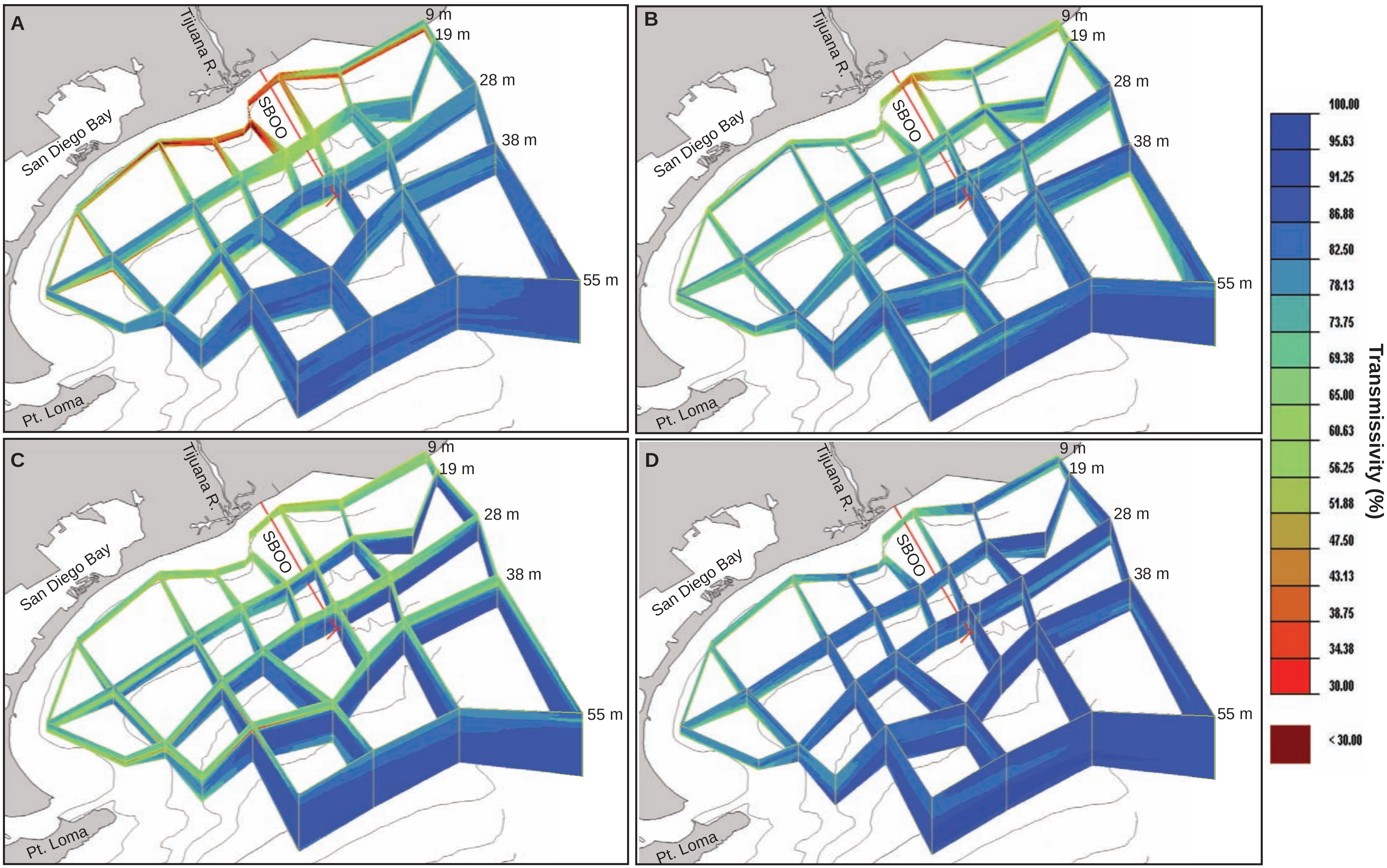
Appendix A.3

Concentrations of dissolved oxygen recorded in 2010 for the SBOO region during (A) February, (B) May, (C) August, and (D) November. Data were collected over three days during each of these monthly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.



Appendix A.4

Vertical profiles of dissolved oxygen for SBOO stations during (A) February, (B) May, (C) August, and (D) November 2010.



Appendix A.5

Transmissivity recorded in 2010 for the SBOO region during (A) February, (B) May, (C) August, and (D) November. Data were collected over three days during each of these monthly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.

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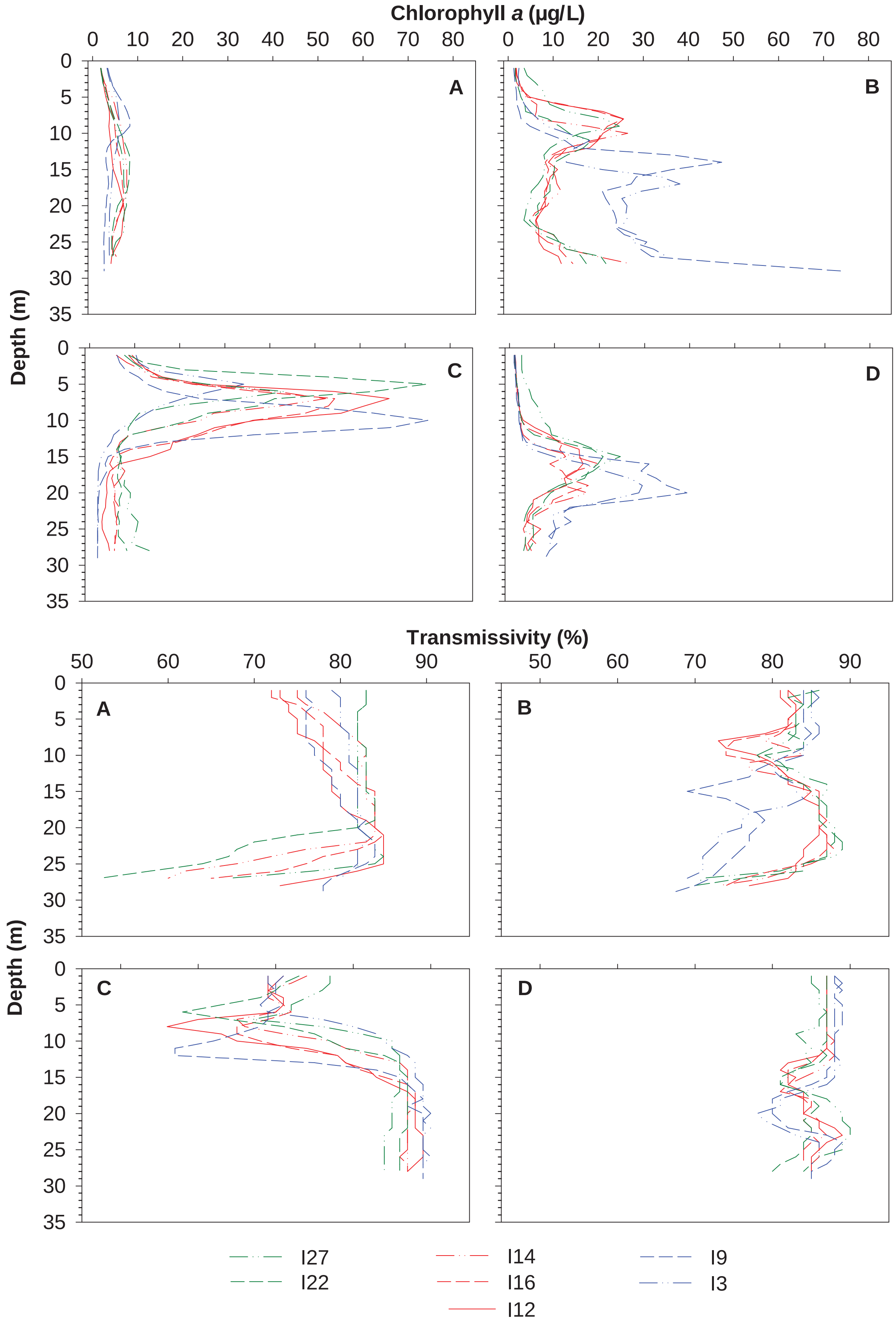
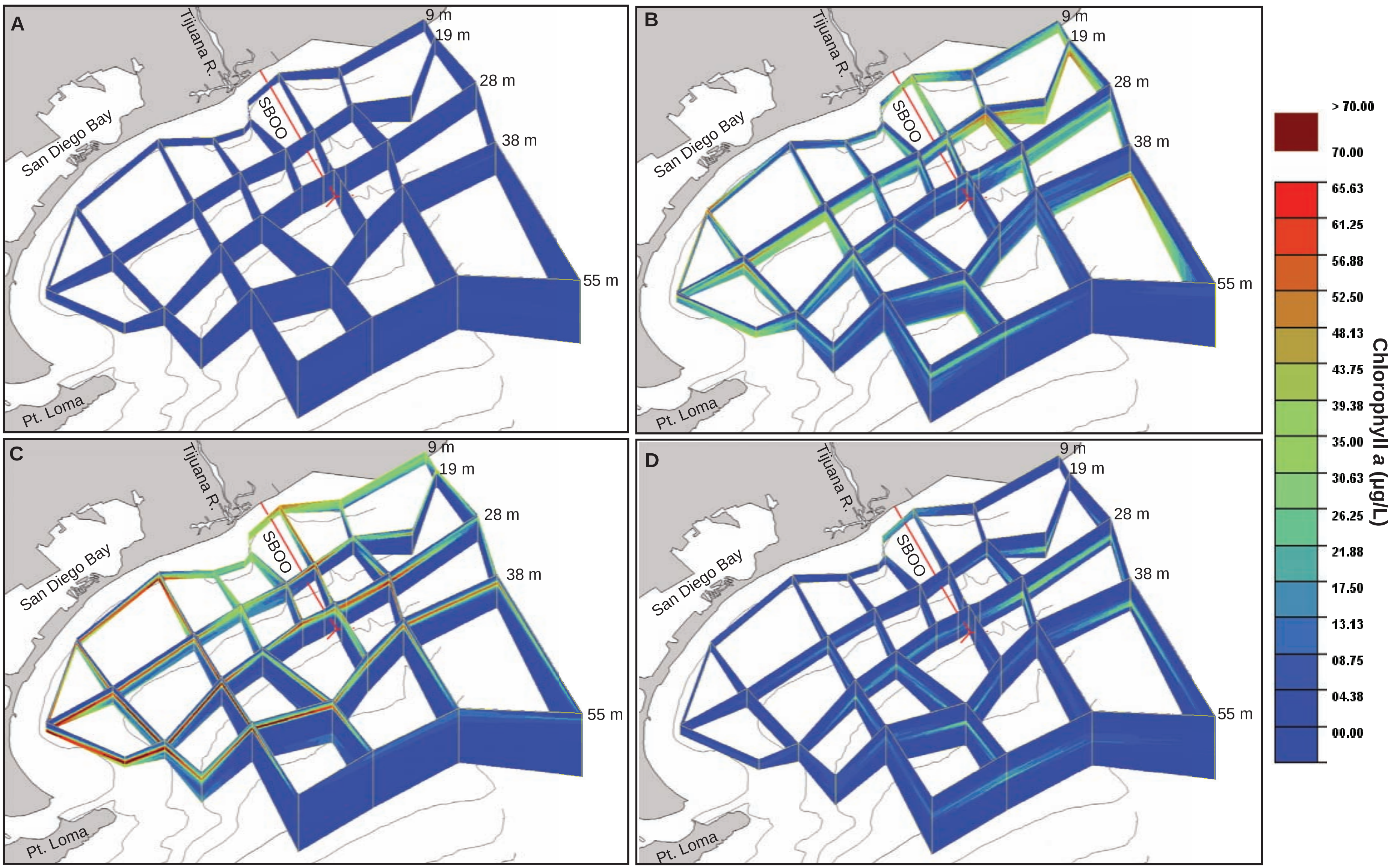


Appendix A.6

Vertical profiles of chlorophyll *a* and transmissivity for SBOO stations during (A) February, (B) May, (C) August, and (D) November 2010.



Appendix A.7

Concentrations of chlorophyll *a* recorded in 2010 for the SBOO region during (A) February, (B) May, (C) August, and (D) November. Data were collected over three days during each of these monthly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.

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Appendix B

Supporting Data

2010 SBOO Stations

Water Quality

Appendix B.1

Summary of samples with elevated (bold) total coliform (>10,000 CFU/100 mL), fecal coliform (>400 CFU/100 mL), and/or enterococcus (>104 CFU/100 mL) densities collected at SBOO shore stations during 2010. Bold fecal:total coliform (F:T) values indicate samples which meet the FTR criterion for contamination (i.e., total coliforms >1000 CFU/100 mL and F:T>0.10).

Station	Date	Total	Fecal	Entero	F:T
S0	05 Jan 2010	2600	300	**520**	**0.12**
S5	05 Jan 2010	**>16,000**	**4400**	**5000**	**0.28**
S0	12 Jan 2010	480	60	**460**	0.13
S0	19 Jan 2010	**13,000**	320	**3000**	0.02
S2	19 Jan 2010	**>16,000**	**1200**	**6800**	0.08
S3	19 Jan 2010	**>16,000**	**600**	**3000**	0.04
S4	19 Jan 2010	**>16,000**	**5800**	**>12,000**	**0.36**
S5	19 Jan 2010	**>16,000**	**3000**	**6200**	**0.19**
S6	19 Jan 2010	**>16,000**	**1200**	**6600**	0.08
S8	19 Jan 2010	1400	72	**160**	0.05
S10	19 Jan 2010	**>16,000**	**4800**	**13000**	**0.30**
S11	19 Jan 2010	**>16,000**	**2800**	**3000**	**0.18**
S12	19 Jan 2010	**>16,000**	**800**	**6200**	0.05
S0	26 Jan 2010	1000	110	**110**	0.11
S2	26 Jan 2010	1400	20	**200**	0.01
S3	26 Jan 2010	**>16,000**	**5600**	**4200**	**0.35**
S4	26 Jan 2010	**>16,000**	**8400**	**3200**	**0.53**
S5	26 Jan 2010	**>16,000**	**>12,000**	**>12,000**	**0.75**
S6	26 Jan 2010	200	16	**160**	0.08
S10	26 Jan 2010	**>16,000**	**>12,000**	**3000**	**0.75**
S12	26 Jan 2010	320	26	**200**	0.08
S0	02 Feb 2010	**>16,000**	**2400**	**3800**	**0.15**
S3	02 Feb 2010	2600	220	**120**	0.08
S12	02 Feb 2010	6	2	**120**	0.33
S0	09 Feb 2010	6400	**700**	**220**	0.11
S2	09 Feb 2010	**>16,000**	340	**260**	0.02
S3	09 Feb 2010	**>16,000**	**>12,000**	**5200**	**0.75**
S4	09 Feb 2010	**>16,000**	**2600**	**300**	**0.16**
S5	09 Feb 2010	**>16,000**	**>12,000**	**>12,000**	**0.75**
S10	09 Feb 2010	**>16,000**	**2200**	**360**	**0.14**
S0	16 Feb 2010	1100	120	20	**0.11**
S3	16 Feb 2010	**>16,000**	**2000**	**3200**	**0.13**
S5	16 Feb 2010	**>16,000**	**780**	32	0.05
S10	16 Feb 2010	**>16,000**	**1100**	62	0.07
S3	23 Feb 2010	**>16,000**	**>12,000**	**>12,000**	**0.75**
S4	23 Feb 2010	**>16,000**	200	**110**	0.01
S5	23 Feb 2010	**>16,000**	**>12,000**	**>12,000**	**0.75**
S10	23 Feb 2010	**>16,000**	**3000**	**1400**	**0.19**
S2	02 Mar 2010	**>16,000**	360	**440**	0.02
S3	02 Mar 2010	**>16,000**	**8800**	**2800**	**0.55**
S4	02 Mar 2010	**11,000**	**500**	**380**	0.05
S5	02 Mar 2010	**>16,000**	**1800**	**280**	**0.11**
S6	02 Mar 2010	**>16,000**	100	32	0.01
S10	02 Mar 2010	**>16,000**	140	100	0.01
S11	02 Mar 2010	**13,000**	140	20	0.01
S0	09 Mar 2010	**>16,000**	400	**620**	0.03
S2	09 Mar 2010	**>16,000**	**580**	**540**	0.04

Appendix B.1 *continued*

Station	Date	Total	Fecal	Entero	F:T
S3	09 Mar 2010	**>16,000**	**>12,000**	**>12,000**	**0.75**
S4	09 Mar 2010	**>16,000**	**1800**	**1200**	**0.11**
S10	09 Mar 2010	**>16,000**	**1200**	**3400**	0.08
S5	16 Mar 2010	**13,000**	120	6	0.01
S10	16 Mar 2010	**13,000**	180	4	0.01
S5	23 Mar 2010	**>16,000**	**>12,000**	**>12,000**	**0.75**
S6	23 Mar 2010	**>16,000**	**820**	28	0.05
S10	23 Mar 2010	**>16,000**	120	2	0.01
S4	06 Apr 2010	**13,000**	300	8	0.02
S10	06 Apr 2010	**14,000**	**480**	2	0.03
S5	13 Apr 2010	**>16,000**	**>12,000**	**>12,000**	**0.75**
S10	13 Apr 2010	**>16,000**	**640**	92	0.04
S6	27 Apr 2010	**>16,000**	400	10	0.03
S11	27 Apr 2010	**>16,000**	160	6	0.01
S0	04 May 2010	820	200	**240**	0.24
S5	04 May 2010	**>16,000**	**4600**	**2200**	**0.29**
S11	04 May 2010	**>16,000**	260	14	0.02
S8	18 May 2010	180	54	**140**	0.30
S0	19 May 2010	600	140	**260**	0.23
S0	25 May 2010	720	130	**110**	0.18
S0	01 Jun 2010	3800	**1800**	60	**0.47**
S0	08 Jun 2010	6800	**600**	**1100**	0.09
S2	29 Jun 2010	20	14	**260**	0.70
S0	06 Jul 2010	1500	100	**120**	0.07
S0	13 Jul 2010	**11,000**	**700**	**940**	0.06
S0	20 Jul 2010	4600	**420**	**140**	0.09
S2	20 Jul 2010	1400	320	66	**0.23**
S0	26 Aug 2010	400	56	**110**	0.14
S0	31 Aug 2010	**3000**	360	**140**	**0.12**
S0	07 Sep 2010	1400	300	**180**	**0.21**
S5	05 Oct 2010	1600	200	8	**0.13**
S9	19 Oct 2010	3400	**960**	**1200**	**0.28**
S0	26 Oct 2010	**>16,000**	**1400**	**940**	0.09
S3	26 Oct 2010	660	160	**640**	0.24
S5	26 Oct 2010	1200	260	100	**0.22**
S6	26 Oct 2010	1800	340	**360**	**0.19**
S11	26 Oct 2010	400	220	**180**	0.55
S5	02 Nov 2010	60	34	**120**	0.57
S0	09 Nov 2010	5400	180	**340**	0.03
S3	09 Nov 2010	20	6	**320**	0.30

Appendix B.1 *continued*

Station	Date	Total	Fecal	Entero	F:T
S0	23 Nov 2010	1000	92	**130**	0.09
S2	23 Nov 2010	2400	120	16	0.05
S3	23 Nov 2010	3400	150	20	0.04
S4	23 Nov 2010	**>16,000**	**680**	18	0.04
S10	23 Nov 2010	**>16,000**	**1600**	54	**0.10**
S0	07 Dec 2010	7200	260	**680**	0.04
S0	21 Dec 2010	**>16,000**	**7200**	**>12,000**	**0.45**
S2	21 Dec 2010	**>16,000**	**3600**	**8200**	**0.23**
S3	21 Dec 2010	**>16,000**	**>12,000**	**>12,000**	**0.75**
S5	21 Dec 2010	**>16,000**	**>12,000**	**>12,000**	**0.75**
S6	21 Dec 2010	**>16,000**	**3000**	**10,000**	**0.19**
S8	21 Dec 2010	**>16,000**	**1400**	**2000**	0.09
S9	21 Dec 2010	**>16,000**	**880**	**2800**	0.06
S11	21 Dec 2010	**>16,000**	**>12,000**	**>12,000**	**0.75**
S12	21 Dec 2010	**>16,000**	**2200**	**6200**	**0.14**
S0	28 Dec 2010	3200	70	**120**	0.02
S2	28 Dec 2010	1600	80	**340**	0.05
S4	28 Dec 2010	**>16,000**	**2000**	**240**	**0.13**
S5	28 Dec 2010	1600	120	**240**	0.08
S10	28 Dec 2010	**>16,000**	**>12,000**	**3000**	**0.75**
S11	28 Dec 2010	600	140	**560**	0.23

Appendix B.2

Summary of samples with elevated (bold) total coliform (>10,000 CFU/100 mL), fecal coliform (>400 CFU/100 mL), and/or enterococcus (>104 CFU/100 mL) densities collected at SBOO kelp bed stations during 2010. Bold fecal:total coliform (F:T) values indicate samples which meet the FTR criterion for contamination (i.e., total coliforms >1000 CFU/100 mL and F:T>0.10).

Station	Date	Depth (m)	Total	Fecal	Entero	F:T
I25	25 Jan 2010	2	1200	36	**120**	0.03
I25	25 Jan 2010	6	2400	42	**400**	0.02
I25	25 Jan 2010	9	1600	52	**540**	0.03
I26	25 Jan 2010	2	420	8	**110**	0.02
I26	25 Jan 2010	6	2800	74	**480**	0.03
I26	25 Jan 2010	9	1600	110	**1100**	0.07
I39	25 Jan 2010	12	480	32	**480**	0.07
I39	25 Jan 2010	18	320	20	**120**	0.06
I26	28 Jan 2010	9	900	14	**180**	0.02
I25	11 Feb 2010	2	**>16,000**	**520**	**360**	0.03
I25	11 Feb 2010	9	**12,000**	240	**380**	0.02
I39	11 Feb 2010	2	3600	400	**260**	**0.11**
I26	17 Feb 2010	6	**11,000**	200	20	0.02
I25	24 Feb 2010	2	**12,000**	**640**	52	0.05
I25	01 Apr 2010	9	2600	320	42	**0.12**
I39	18 May 2010	18	1600	**540**	100	**0.34**
I26	02 Oct 2010	2	**>16,000**	**5400**	**500**	**0.34**
I39	02 Oct 2010	2	**>16,000**	**3000**	**280**	**0.19**
I26	20 Oct 2010	2	**>16,000**	**>12,000**	**>12,000**	**0.75**
I26	20 Oct 2010	9	**>16,000**	**3600**	**3600**	**0.23**
I39	06 Nov 2010	12	4	2	**110**	0.50
I25	23 Nov 2010	2	9600	**820**	**240**	0.09
I25	28 Dec 2010	2	100	34	**110**	0.34
I25	28 Dec 2010	6	400	54	**380**	0.14
I25	28 Dec 2010	9	1800	260	**1300**	**0.14**
I26	28 Dec 2010	6	100	78	**480**	0.78
I26	28 Dec 2010	9	2400	86	**880**	0.04

Appendix B.3

Summary of samples with elevated (bold) total coliform (>10,000 CFU/100 mL), fecal coliform (>400 CFU/100 mL), and/or enterococcus (>104 CFU/100 mL) densities collected at SBOO offshore stations during 2010. Bold fecal:total coliform (F:T) values indicate samples which meet the FTR criterion for contamination (i.e., total coliform >1000 CFU/100 mL and F:T>0.10).

Station	Date	Depth (m)	Total	Fecal	Entero	F:T
I12	05 Jan 2010	2	**>16,000**	**7000**	**5400**	**0.44**
I16	05 Jan 2010	2	**>16,000**	**4600**	**2400**	**0.29**
I12	23 Feb 2010	2	**>16,000**	**740**	40	0.05
I12	23 Feb 2010	27	**15,000**	320	18	0.02
I19	23 Feb 2010	2	**>16,000**	**440**	**200**	0.03
I40	23 Feb 2010	2	**>16,000**	340	96	0.02
I9	25 Feb 2010	18	9600	**1600**	**160**	**0.17**
I32	08 Mar 2010	2	**>16,000**	**2600**	**2000**	**0.16**
I32	08 Mar 2010	6	**>16,000**	**1200**	**2200**	0.08
I32	08 Mar 2010	9	**>16,000**	**520**	**440**	0.03
I36	08 Mar 2010	2	**>16,000**	**1300**	**280**	0.08
I12	15 Mar 2010	18	**>16,000**	**>12,000**	**4200**	**0.75**
I16	17 Mar 2010	18	**>16,000**	**4800**	**1100**	**0.30**
I16	02 Jun 2010	18	**>16,000**	**11,000**	**2800**	**0.69**
I30	03 Jun 2010	18	2200	380	**180**	**0.17**
I9	13 Jul 2010	18	5400	**2200**	**480**	**0.41**
I12	14 Jul 2010	18	**>16,000**	**>12,000**	**8400**	**0.75**
I12	14 Jul 2010	27	**>16,000**	**8400**	**2000**	**0.53**
I30	02 Aug 2010	18	1000	**480**	100	0.48
I30	07 Sep 2010	18	3000	**760**	**320**	**0.25**
I16	08 Sep 2010	18	**11,000**	**4800**	**1200**	**0.44**
I16	14 Oct 2010	18	4400	**1200**	**360**	**0.27**
I16	14 Oct 2010	27	4800	**1200**	**200**	**0.25**
I12	16 Nov 2010	18	**>16,000**	**1200**	40	0.08
I16	16 Nov 2010	18	**>16,000**	**5000**	40	**0.31**
I18	16 Nov 2010	12	3600	**440**	**280**	**0.12**

Appendix B.4

Summary of compliance with the 2001 California Ocean Plan water contact standards for SBOO shore and kelp bed stations from January 1 – July 31, 2010. The values reflect the number of days that each station exceeded the 30-day total coliform, 10,000 total coliform, the 60-day fecal coliform, and 30-day fecal geometric mean standards (see Chapter 3; Box 3.1). Shore stations are listed north to south from left to right.

	Shore Stations								Kelp Bed Stations		
Month	**S9**	**S8**	**S12**	**S6**	**S11**	**S5**	**S10**	**S4**	**I25**	**I26**	**I39**
30-day Total Coliform Standard											
January	0	15	20	20	18	31	31	31	7	5	0
February	0	11	17	27	26	28	28	28	28	21	2
March	0	0	0	31	10	31	31	31	18	18	0
April	0	0	0	7	0	30	30	30	0	0	0
May	0	0	0	0	23	26	6	10	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0
Percent Compliance	**100%**	**88%**	**83%**	**60%**	**64%**	**31%**	**41%**	**39%**	**75%**	**79%**	**99%**
10,000 Total Coliform Standard											
January	0	0	1	1	1	2	1	1	0	0	0
February	0	0	0	0	0	2	2	1	0	0	0
March	0	0	0	0	0	1	1	1	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**1**	**1**	**1**	**5**	**4**	**3**	**0**	**0**	**0**
60-day Fecal Coliform Standard											
January	0	14	31	13	22	31	31	31	0	0	0
February	0	1	28	28	28	28	28	28	0	0	0
March	0	0	19	19	19	31	31	31	0	0	0
April	0	0	0	0	0	30	30	30	0	0	0
May	0	0	0	0	0	31	31	0	0	0	0
June	0	0	0	0	0	19	6	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0
Percent Compliance	**100%**	**93%**	**63%**	**72%**	**67%**	**20%**	**26%**	**43%**	**100%**	**100%**	**100%**
30-day Fecal Geometric Mean Standard											
January	0	0	0	0	0	18	8	4	0	0	0
February	0	0	0	0	0	28	28	16	0	0	0
March	0	0	0	0	0	29	24	8	0	0	0
April	0	0	0	0	0	4	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0
Percent Compliance	**100%**	**100%**	**100%**	**100%**	**100%**	**63%**	**72%**	**87%**	**100%**	**100%**	**100%**

Appendix B.5

Summary of compliance with the 2005 California Ocean Plan water contact standards for SBOO shore and kelp bed stations from August 1 – December 31, 2010. The values reflect the number of times per month that each station exceeded various total coliform, fecal coliform, and enterococcus bacterial standards (see Chapter 3; Box 3.1). Shore stations are listed north to south from left to right.

30-day Geometric Mean Standards

	Shore Stations								Kelp Bed Stations		
Month	**S9**	**S8**	**S12**	**S6**	**S11**	**S5**	**S10**	**S4**	**I25**	**I26**	**I39**
Total Coliform											
August	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	7	0	0	0	0	0
Percent Compliance	**100%**	**100%**	**100%**	**100%**	**100%**	**95%**	**100%**	**100%**	**100%**	**100%**	**100%**
Fecal Coliform											
August	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0
Percent Compliance	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Enterococcus											
August	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0
October	6	0	0	0	0	0	0	0	0	9	0
November	6	0	0	5	0	0	0	0	0	10	0
December	7	9	9	9	9	11	2	2	0	0	0
Percent Compliance	**88%**	**94%**	**94%**	**91%**	**94%**	**93%**	**99%**	**99%**	**100%**	**88%**	**100%**

Appendix B.5 *continued*

Single Sample Maximum Standards

	Shore Stations								Kelp Bed Stations		
Month	**S9**	**S8**	**S12**	**S6**	**S11**	**S5**	**S10**	**S4**	**I25**	**I26**	**I39**
Total Coliform											
August	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	1	0	0	0	0	0	2	1
November	0	0	0	0	0	0	1	1	0	0	0
December	2	2	2	2	2	3	2	2	0	0	0
Total	**2**	**2**	**2**	**3**	**2**	**3**	**3**	**3**	**0**	**2**	**1**
Fecal Coliform											
August	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0
October	1	0	0	1	0	0	0	0	0	3	1
November	0	0	0	0	0	0	1	1	1	0	0
December	2	2	2	2	2	3	2	2	0	0	0
Total	**3**	**2**	**2**	**3**	**2**	**3**	**3**	**3**	**1**	**3**	**1**
Enterococcus											
August	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0
October	1	0	0	1	1	0	0	0	0	4	1
November	0	0	0	0	0	1	0	0	1	0	1
December	2	2	4	4	6	6	2	2	3	3	0
Total	**3**	**2**	**4**	**5**	**7**	**7**	**2**	**2**	**4**	**7**	**2**
Fecal/Total Coliform Ratio (F:T)											
August	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0
October	1	0	0	1	0	2	0	0	0	3	1
November	0	0	0	0	0	0	0	0	0	0	0
December	1	1	2	2	2	2	2	2	1	0	0
Total	**2**	**1**	**2**	**3**	**2**	**4**	**2**	**2**	**1**	**3**	**1**

Appendix C

Supporting Data

2010 SBOO Stations

Sediment Conditions

Appendix C.1

A subset of the Wentworth scale (based on Folk 1980) and modifications used in the analysis of sediments from the SBOO region in 2010. The modified scale was developed to accommodate data output from the Horiba laser analyzer. Particle size is presented in microns, millimeters, and phi size along with descriptions of each size range and how they are classified within size fractions.

Wentworth Scale

Original	Modified				
Microns	Microns	Millimeters	Phi size	Description	Fraction
≥2000	≥1681	≥1.681	≤-1	Granules–Pebbles	Coarse
1000–1999	931–1680	0.931–1.680	0	Very coarse sand	
500–999	441–930	0.441–0.930	1	Coarse sand	Sand
250–499	246–440	0.246–0.440	2	Medium sand	
125–249	106–245	0.106–0.245	3	Fine sand	
62.5–124	54–105	0.054–0.105	4	Very fine sand	
31–62.4	28–53	0.028–0.053	5	Coarse silt	Silt
15.6–30.9	14.9–27	0.0149–0.027	6	Medium silt	
7.8–15.5	6.0–14.8	0.0060–0.0148	7	Fine silt	
3.9–7.7	3.5–5.9	0.0035–0.0059	8	Very fine silt	
2.0–3.8	1.6–3.4	0.0016–0.0034	9	Clay	Clay
0.98–1.9	0.51–1.5	0.00051–0.0015	10	Clay	
≤0.97	≤0.50	≤0.00050	11	Clay	

Appendix C.2

Constituents and method detection limits (MDLs) for sediment samples analyzed for the SBOO monitoring program during 2010.

Parameter	MDL	Parameter	MDL
Organic Indicators			
Total Sulfides (ppm)	0.14	Total Organic Carbon (% weight)	0.01
Total Nitrogen (% weight)	0.005		
Metals (ppm)			
Aluminum (Al)	2	Lead (Pb)	0.8
Antimony (Sb)	0.3	Manganese (Mn)	0.08
Arsenic (As)	0.33	Mercury (Hg)	0.003
Barium (Ba)	0.02	Nickel (Ni)	0.1
Beryllium (Be)	0.01	Selenium (Se)	0.24
Cadmium (Cd)	0.06	Silver (Ag)	0.04
Chromium (Cr)	0.1	Thallium (Tl)	0.5
Copper (Cu)	0.2	Tin (Sn)	0.3
Iron (Fe)	9	Zinc (Zn)	0.25
Chlorinated Pesticides (ppt)			
Hexachlorocyclohexane (HCH)			
HCH, Alpha isomer	400	HCH, Delta isomer	400
HCH, Beta isomer	400	HCH, Gamma isomer	400
Total Chlordane			
Alpha (cis) Chlordane	700	Heptachlor epoxide	700
Cis Nonachlor	700	Methoxychlor	700
Gamma (trans) Chlordane	700	Oxychlordane	700
Heptachlor	700	Trans Nonachlor	700
Total Dichlorodiphenyltrichloroethane (DDT)			
o,p-DDD	400	p,p-DDE	400
o,p-DDE	700	p,p-DDMU	*
o,p-DDT	700	p,p-DDT	700
p,p-DDD	700		
Miscellaneous Pesticides			
Aldrin	700	Endrin	700
Alpha Endosulfan	700	Endrin aldehyde	700
Beta Endosulfan	700	Hexachlorobenzene (HCB)	400
Dieldrin	700	Mirex	700
Endosulfan Sulfate	700		

* No MDL available for this parameter

Appendix C.2 *continued*

Parameter	MDL	Parameter	MDL
Polychlorinated Biphenyl Congeners (PCBs) (ppt)			
PCB 18	700	PCB 126	1500
PCB 28	700	PCB 128	700
PCB 37	700	PCB 138	700
PCB 44	700	PCB 149	700
PCB 49	700	PCB 151	700
PCB 52	700	PCB 153/168	700
PCB 66	700	PCB 156	700
PCB 70	700	PCB 157	700
PCB 74	700	PCB 158	700
PCB 77	700	PCB 167	700
PCB 81	700	PCB 169	700
PCB 87	700	PCB 170	700
PCB 99	700	PCB 177	700
PCB 101	700	PCB 180	400
PCB 105	700	PCB 183	700
PCB 110	700	PCB 187	700
PCB 114	700	PCB 189	400
PCB 118	700	PCB 194	700
PCB 119	700	PCB 201	700
PCB 123	700	PCB 206	700
Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)			
1-methylnaphthalene	20	Benzo[G,H,I]perylene	20
1-methylphenanthrene	20	Benzo[K]fluoranthene	20
2,3,5-trimethylnaphthalene	20	Biphenyl	30
2,6-dimethylnaphthalene	20	Chrysene	40
2-methylnaphthalene	20	Dibenzo(A,H)anthracene	20
3,4-benzo(B)fluoranthene	20	Fluoranthene	20
Acenaphthene	20	Fluorene	20
Acenaphthylene	30	Indeno(1,2,3-CD)pyrene	20
Anthracene	20	Naphthalene	30
Benzo[A]anthracene	20	Perylene	30
Benzo[A]pyrene	20	Phenanthrene	30
Benzo[e]pyrene	20	Pyrene	20

Appendix C.3

Summary of the constituents that make up tDDT and tPCB in each sediment sample collected as part of the SBOO monitoring program during 2010.

Station	Class	Constituent	January	July	Units
I1	DDT	p,p-DDE	58	nd	ppt
I6	DDT	p,p-DDT	76	nd	ppt
I7	DDT	p,p-DDE	80	nd	ppt
I12	DDT	p,p-DDE	91	nd	ppt
I14	DDT	p,p-DDE	130	nd	ppt
I16	DDT	p,p-DDE	110	nd	ppt
I21	DDT	p,p-DDE	110	nd	ppt
I22	DDT	p,p-DDE	47	nd	ppt
I23	DDT	p,p-DDE	85	nd	ppt
I27	DDT	p,p-DDE	170	nd	ppt
I28	DDT	p,p-DDE	680	630	ppt
I28	PCB	PCB 138	130	nd	ppt
I28	PCB	PCB 149	94	nd	ppt
I28	PCB	PCB 153/168	66	74	ppt
I29	DDT	p,p-DDE	1100	1100	ppt

nd = not detected

Appendix C.4

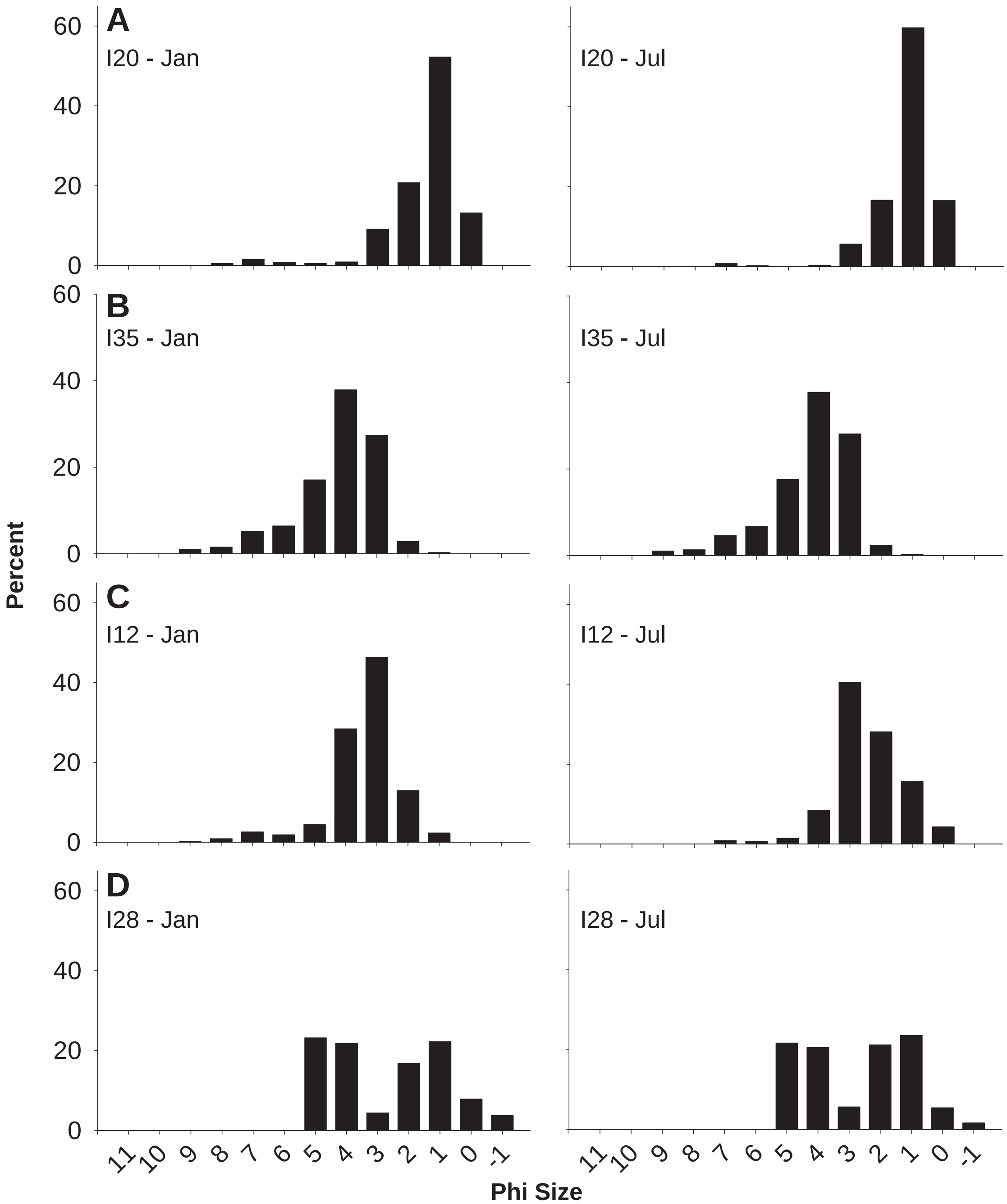
SBOO sediment statistics for the January 2010 survey. Silt and clay fractions are indiscernable for samples analyzed by sieve. Visual observations of sediments were made in the field at the time of collection as well as on the sieved “grunge” (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis). *=nearfield stations; Skew.=skewness; Kurt.=kurtosis; Pre-discharge period=1995–1998.

	Depth (m)	Mean (mm)	Mean (phi)	SD (phi)	Median (phi)	Skew. (phi)	Kurt. (phi)	Coarse (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	Visual Observations
19-m Stations													
I35	19	0.080	3.65	1.19	3.5	0.3	1.3	0.0	68.5	30.3	1.2	31.5	Clay and silt, organic worm tube debris
I34	19	0.295	1.76	0.87	1.9	-0.3	0.9	4.3	95.6	0.1	0.0	0.1	Sand, shell hash
I31	19	0.116	3.11	0.66	3.1	0.2	1.2	0.0	92.5	7.4	0.0	7.4	Silt with clay
I23	21	0.111	3.18	0.83	3.1	0.3	1.5	0.0	88.3	11.4	0.3	11.6	Fine sand and silt and shell hash
I18	19	0.112	3.16	0.70	3.1	0.2	1.3	0.0	90.4	9.5	0.1	9.6	Fine sand and silt and shell hash
I10	19	0.115	3.12	0.67	3.1	0.2	1.2	0.0	91.8	8.2	0.0	8.2	Fine sand and silt
I4	18	0.489	1.03	0.77	1.0	0.1	1.0	7.0	92.8	0.1	0.0	0.1	Fine sand with shell hash
28-m Stations													
I33	30	0.125	3.00	0.81	3.0	0.3	5.0	0.0	88.8	10.7	0.4	11.2	Silt, organic worm tube debris
I30	28	0.099	3.34	0.85	3.3	0.3	1.8	0.0	83.6	15.9	0.5	16.4	Silt with fine sand, worm tubes, kelp debris
I27	28	0.102	3.29	0.85	3.3	0.2	1.6	0.0	85.5	13.9	0.6	14.5	Silt and fine sand
I22	28	0.112	3.16	0.96	3.1	0.3	2.0	0.0	85.3	14.1	0.6	14.7	Silt with fine sand, worm tubes, shell hash
I14*	28	0.105	3.26	0.75	3.2	0.4	1.7	0.0	86.6	13.1	0.3	13.4	Silt, organic worm tube debris
I16*	28	0.141	2.83	1.01	2.7	0.2	1.5	0.0	90.0	9.7	0.3	9.9	Fine sand, silt, worm tubes, shell hash
I15*	31	0.420	1.25	0.79	1.3	0.0	0.9	5.5	94.2	0.2	0.0	0.2	Fine sand and sand
I12*	28	0.145	2.79	0.96	2.8	0.1	1.8	0.0	90.1	9.7	0.2	9.9	Fine sand, silt, worm tubes, shell hash
I9	29	0.097	3.37	0.90	3.3	0.2	1.7	0.0	83.1	16.3	0.6	16.9	Silt, fine sand, organic worm tube debris
I6	26	0.527	0.92	0.75	0.9	0.2	1.0	8.8	91.2	0.1	0.0	0.1	Fine red relict sand, fine sand, shell hash
I2	32	0.280	1.83	0.62	1.8	0.0	0.9	0.0	98.5	1.5	0.0	1.5	Fine sand
I3	27	0.642	0.64	0.73	0.6	0.3	1.4	15.9	80.9	3.2	0.0	3.2	Lots of red relict sand and fine sand
38-m Stations													
I29	38	0.084	3.57	1.14	3.4	0.3	1.5	0.0	74.4	24.3	1.3	25.6	Silt, coarse sand, organic worm tube debris
I21	41	0.544	0.88	0.70	0.8	0.1	1.0	8.8	91.2	0.0	0.0	0.0	Fine red relict sand, shell debris
I13	38	0.423	1.24	1.47	1.3	0.3	1.7	4.9	83.9	10.6	0.5	11.2	Sand, lots of red relict sand, shell hash
I8	36	0.383	1.38	0.87	1.4	-0.1	0.9	5.1	92.9	2.0	0.0	2.0	Fine sand
55-m Stations													
I28	55	0.233	2.10	1.68	1.9	0.1	0.7	11.7	65.2	—	—	23.1	Silt, fine sand, coarse black sand, shell hash
I20	55	0.540	0.89	0.93	0.7	0.3	1.2	13.3	83.1	3.6	0.0	3.6	Coarse sand, red relict sand, and shell hash
I7	52	0.474	1.08	0.75	0.9	0.2	2.2	10.8	87.6	1.6	0.0	1.6	Sand, coarse red relict sand, shell hash
I1	60	0.139	2.85	0.88	2.9	0.1	2.8	0.0	92.0	7.9	0.1	8.0	Fine sand
January Max		0.642	3.65	1.68	3.5	0.4	5.0	15.9	98.5	30.3	1.3	31.5	
Pre-discharge Max		0.758	4.20	2.50	3.9	0.8	7.4	52.5	100.0	44.0	5.3	47.2	

Appendix C.4 *continued*

SBOO sediment statistics for the July 2010 survey. Silt and clay fractions are indiscernable for samples analyzed by sieve. Visual observations of sediments were made in the field at the time of collection as well as on the sieved "grunge" (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis). *=nearfield stations; Skew.=skewness; Kurt.=kurtosis; Pre-discharge period=1995–1998.

	Depth (m)	Mean (mm)	Mean (phi)	SD (phi)	Median (phi)	Skew. (phi)	Kurt. (phi)	Coarse (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	Visual Observations
19-m Stations													
I35	19	0.080	3.64	1.16	3.5	0.3	1.2	0.0	68.5	30.3	1.2	31.5	Fine sand with silt, organic worm tube debris
I34	19	0.371	1.43	0.90	1.4	0.0	0.9	5.4	92.3	2.3	0.0	2.3	Sand with fine sand and coarse shell hash
I31	19	0.120	3.06	0.48	3.0	0.3	3.1	0.0	92.3	7.6	0.1	7.7	Fine sand with silt
I23	21	0.140	2.84	1.35	3.4	-0.6	1.2	5.4	80.6	—	—	14.0	Fine sand with coarse shell hash, worm tube debris
I18	19	0.114	3.14	0.64	3.1	0.2	1.2	0.0	92.2	7.8	0.0	7.8	Fine sand with silt
I10	19	0.114	3.13	0.71	3.1	0.2	1.3	0.0	90.9	9.0	0.1	9.1	Silt with fine sand
I4	18	0.587	0.77	0.67	0.7	0.1	1.1	11.4	88.6	0.0	0.0	0.0	Sand, fine sand, silt, gravel, shell hash, worm tubes
28-m Stations													
I33	30	0.123	3.02	0.96	2.9	0.4	1.8	0.0	88.9	10.5	0.6	11.1	Silt, some organic worm tube debris
I30	28	0.099	3.33	0.74	3.3	0.2	1.4	0.0	85.7	13.9	0.4	14.3	Silt
I27	28	0.101	3.30	0.68	3.2	0.3	1.4	0.0	87.1	12.5	0.3	12.9	Silt
I22	28	0.111	3.17	0.89	3.1	0.3	1.5	0.0	86.8	12.7	0.4	13.1	Silt with fine sand, organic worm tube debris
I14*	28	0.102	3.29	0.89	3.3	0.2	1.6	0.0	84.5	14.7	0.7	15.4	Silt with fine sand
I16*	28	0.168	2.57	0.78	2.5	0.1	1.3	0.0	95.0	5.0	0.0	5.0	Silt with fine sand
I15*	31	0.352	1.50	1.05	1.6	0.0	1.2	5.6	90.2	4.2	0.0	4.2	Sand with fine sand
I12*	28	0.267	1.91	1.02	2.1	-0.2	1.0	4.3	92.8	2.9	0.0	2.9	Silt with fine sand, worm tube debris, shell hash
I9	29	0.098	3.35	0.73	3.3	0.2	1.4	0.0	84.7	14.9	0.4	15.3	Silt with fine sand, organic worm tube debris
I6	26	0.549	0.86	0.75	0.8	0.2	1.0	10.2	89.8	0.0	0.0	0.0	Fine red relict sand, shell hash
I2	32	0.283	1.82	0.61	1.8	0.0	0.9	0.0	98.7	1.2	0.0	1.2	Sand
I3	27	0.510	0.97	0.72	0.9	0.1	0.9	6.9	93.1	0.0	0.0	0.0	Sand and red relict sand
38-m Stations													
I29	38	0.096	3.39	1.20	3.2	0.3	1.5	0.0	77.5	21.4	1.1	22.5	Silt, coarse red relict and black sand, organics
I21	41	0.470	1.09	0.79	1.1	0.1	1.0	6.8	93.2	0.0	0.0	0.0	Fine red relict sand, shell hash
I13	38	0.559	0.84	0.70	0.8	0.1	1.0	9.8	90.2	0.0	0.0	0.0	Sand, coarse red relict sand, shell hash
I8	36	0.521	0.94	0.76	0.9	0.2	0.9	10.1	89.9	0.0	0.0	0.0	Sand, some fine sand, organic worm tube debris
55-m Stations													
I28	55	0.224	2.16	1.59	1.9	0.1	0.6	7.2	71.1	—	—	21.7	Silt with gravel and lots of coarse black sand
I20	55	0.639	0.65	0.71	0.6	0.3	1.2	16.5	82.3	1.1	0.0	1.1	Red relict sand, coarse black sand, shell hash
I7	52	0.660	0.60	0.69	0.4	0.4	1.1	15.6	84.4	0.0	0.0	0.0	Red relict sand with sand, shell hash
I1	60	0.124	3.02	0.89	3.0	0.3	2.7	0.0	90.3	9.3	0.3	9.7	Silt with fine sand
July Max		0.660	3.64	1.59	3.5	0.4	3.1	16.5	98.7	30.3	1.2	31.5	
Pre-discharge Max		0.758	4.20	2.50	3.9	0.8	7.4	52.5	100.0	44.0	5.3	47.2	



Appendix C.5

Select histograms illustrating particle size distributions of SBOO sediments in 2010. (A) Station with the highest percent coarse material (I20); (B) Station with the highest percent fines (I35); (C) Nearfield station I12, located ~150 m from south diffuser leg of the SBOO; (D) Bimodal distribution at I28. The samples from station I28 were sieved, and so the bar at phi 5 represents all material finer than phi 4 (see text). Note the consistency in shape between January and July surveys within a particular station.

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Appendix C.6

Summary of organic loading indicators at SBOO benthic stations for the January and July 2010 surveys; * = nearfield stations.

	January					July				
	Depth (m)	Sulfides (ppm)	TN (% wt)	TOC (% wt)		Depth (m)	Sulfides (ppm)	TN (% wt)	TOC (% wt)
19-m Stations					*19-m Stations*				
I35	19	0.99	0.033	0.330	I35	19	2.79	0.035	0.236
I34	19	0.67	0.011	0.130	I34	19	1.60	0.027	0.037
I31	19	0.81	0.016	0.116	I31	19	nd	0.023	0.058
I23	21	2.23	0.017	0.132	I23	21	1.51	0.025	0.089
I18	19	0.76	0.016	0.115	I18	19	nd	0.015	0.063
I10	19	0.73	0.015	0.117	I10	19	0.51	0.018	0.092
I4	18	0.96	0.011	0.126	I4	18	0.81	0.009	nd
28-m Stations					*28-m Stations*				
I33	30	1.37	0.023	0.385	I33	30	4.00	0.029	0.176
I30	28	0.85	0.023	0.219	I30	28	4.72	0.026	0.175
I27	28	1.38	0.021	0.202	I27	28	4.15	0.019	0.104
I22	28	0.65	0.026	0.225	I22	28	2.75	0.026	0.168
I14*	28	1.04	0.026	0.265	I14*	28	1.51	0.022	0.127
I16*	28	1.11	0.017	0.131	I16*	28	1.51	0.013	0.044
I15*	31	0.30	0.013	0.064	I15*	31	nd	0.015	0.068
I12*	28	2.80	0.017	0.123	I12*	28	1.08	0.015	0.058
I9	29	1.77	0.023	0.206	I9	29	0.95	0.024	0.134
I6	26	0.16	0.011	0.091	I6	26	nd	0.010	0.019
I2	32	0.23	0.013	0.059	I2	32	0.40	0.011	0.027
I3	27	nd	0.011	0.046	I3	27	0.41	0.007	0.021
38-m Stations					*38-m Stations*				
I29	38	0.90	0.035	0.459	I29	38	1.58	0.033	0.235
I21	41	0.24	0.012	0.058	I21	41	0.44	0.010	0.021
I13	38	0.20	0.012	0.056	I13	38	nd	0.011	0.019
I8	36	0.28	0.013	0.073	I8	36	0.47	0.009	0.017
55-m Stations					*55-m Stations*				
I28	55	0.86	0.037	0.769	I28	55	1.18	0.044	0.395
I20	55	0.23	nd	0.046	I20	55	2.28	0.009	0.014
I7	52	0.32	0.012	0.065	I7	52	0.36	0.011	0.023
I1	60	0.65	0.019	0.230	I1	60	0.55	0.021	0.136
Detection Rate (%)		96	96	100	Detection Rate (%)		81	100	96

nd = not detected

Appendix C.7

Concentrations of trace metals (ppm) for the January 2010 SBOO survey. * = nearfield stations; ERL=Effects Range Low threshold value; ERM=Effects Range Median threshold value. See Appendix C.2 for MDLs and names for each metal represented by periodic table symbol.

	Depth (m)	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
19-m Stations																			
I35	19	7600	nd	1.76	41.20	nd	0.12	11.8	4.30	7760	3.21	86.8	0.017	4.68	nd	nd	nd	0.7	23.6
I34	19	2310	nd	1.45	13.10	nd	nd	3.9	0.91	2900	1.78	27.0	0.005	1.11	nd	nd	nd	nd	7.0
I31	19	3270	nd	0.46	15.80	nd	nd	6.6	1.22	2730	1.01	32.1	nd	1.68	nd	nd	nd	nd	7.8
I23	21	6100	1.18	0.65	33.50	nd	nd	9.6	3.40	5460	1.61	62.2	nd	3.28	nd	nd	nd	0.7	14.6
I18	19	5080	nd	0.94	45.60	nd	nd	11.6	3.46	6450	1.63	68.1	nd	2.73	nd	nd	nd	0.5	14.7
I10	19	7200	nd	0.94	34.70	nd	0.06	10.7	3.34	7030	1.79	76.9	nd	3.18	nd	nd	nd	0.3	17.3
I4	18	933	nd	0.83	2.55	nd	nd	4.5	0.96	1650	1.51	10.4	nd	0.73	nd	nd	nd	nd	3.0
28-m Stations																			
I33	30	4640	nd	1.18	25.80	nd	0.07	8.0	2.91	5350	2.82	62.3	0.013	2.72	nd	nd	nd	0.6	15.3
I30	28	6610	0.33	1.26	31.90	nd	0.08	10.2	2.75	5690	1.68	61.2	nd	3.72	nd	nd	nd	0.7	16.3
I27	28	5620	0.57	0.96	27.80	nd	0.43	10.4	5.25	7040	3.75	58.9	nd	5.94	nd	nd	nd	1.0	19.0
I22	28	5620	1.01	0.75	29.20	nd	nd	9.6	5.52	5430	1.76	56.2	nd	3.64	nd	nd	nd	0.5	15.4
I14*	28	7300	nd	0.91	41.20	nd	nd	11.4	5.42	7500	1.94	79.1	nd	4.16	nd	nd	nd	0.6	21.5
I16*	28	4220	nd	0.67	21.20	nd	nd	7.9	4.34	5010	1.56	55.9	nd	2.15	nd	nd	nd	0.5	12.9
I15*	31	2000	nd	1.65	5.77	nd	nd	8.3	1.41	4080	1.85	23.3	nd	1.25	nd	nd	nd	0.4	8.7
I12*	28	9180	nd	0.99	39.20	nd	0.12	16.9	8.83	11,700	4.86	95.2	nd	8.19	nd	nd	nd	1.2	31.9
I9	29	9700	nd	1.09	46.70	nd	0.08	13.3	4.92	8840	1.85	92.1	nd	4.90	nd	nd	nd	0.4	22.8
I6	26	1420	nd	5.46	3.51	nd	nd	9.4	1.15	6240	2.66	20.7	nd	1.13	nd	nd	nd	nd	7.0
I2	32	1240	nd	nd	2.51	nd	nd	6.3	0.98	1310	1.17	11.5	nd	0.96	nd	nd	nd	nd	2.8
I3	27	933	nd	1.19	1.92	nd	nd	5.8	0.54	2810	1.30	8.8	nd	1.01	nd	nd	nd	nd	3.3
38-m Stations																			
I29	38	7230	nd	1.67	39.40	nd	0.09	11.7	4.08	6850	2.75	69.0	0.011	5.03	nd	nd	nd	1.0	19.8
I21	41	1940	nd	6.18	4.19	nd	nd	11.9	1.95	8320	3.48	15.3	nd	1.63	nd	nd	nd	0.5	8.0
I13	38	1580	nd	6.91	5.33	nd	nd	10.2	2.05	6370	3.11	20.4	nd	1.68	nd	nd	nd	0.4	8.2
I8	36	2120	nd	1.97	5.09	nd	nd	9.8	1.25	4480	1.75	21.7	nd	1.33	nd	nd	nd	nd	8.3
55-m Stations																			
I28	55	6190	nd	2.09	33.00	nd	0.06	9.3	2.66	5370	1.73	59.7	0.019	3.62	nd	nd	nd	0.3	15.9
I20	55	1130	nd	2.62	3.04	nd	nd	4.4	2.86	4480	1.54	15.3	nd	0.84	nd	nd	nd	0.3	6.6
I7	52	1680	nd	2.70	3.77	nd	nd	9.8	0.94	6490	2.78	22.8	nd	1.14	nd	nd	nd	nd	7.0
I1	60	3110	nd	0.86	9.18	nd	0.10	7.3	2.07	3840	2.29	38.9	0.004	2.68	nd	nd	nd	0.6	9.5
Detection Rate (%)		100	15	96	100	0	37	100	100	100	100	100	22	100	0	0	0	70	100
	ERL	na	na	8.2	na	na	1.2	81	34	na	46.7	na	0.15	20.9	na	1	na	na	150
	ERM	na	na	70	na	na	9.6	370	270	na	218	na	0.71	51.6	na	3.7	na	na	410

na=not available; nd=not detected

Appendix C.7 *continued*

Concentrations of trace metals (ppm) for the July 2010 SBOO survey. * = nearfield stations; ERL = Effects Range Low threshold value; ERM = Effects Range Median threshold value. See Appendix C.2 for MDLs and names for each metal represented by periodic table symbol.

	Depth (m)	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
19-m Stations																			
I35	19	5860	nd	2.61	45.80	nd	0.11	11.6	9.06	8800	3.81	84.7	0.017	4.60	nd	nd	nd	0.6	24.6
I34	19	1650	nd	1.93	8.38	nd	nd	3.5	4.45	3060	1.66	23.6	nd	0.93	nd	nd	nd	0.4	6.4
I31	19	3150	nd	1.09	21.70	nd	nd	6.8	4.97	3320	1.19	33.0	0.004	1.71	nd	nd	nd	0.3	7.6
I23	21	3260	nd	1.57	28.10	nd	nd	6.5	5.32	3830	1.23	35.6	0.003	2.09	nd	nd	nd	nd	9.3
I18	19	3860	nd	1.49	35.80	nd	nd	9.8	5.51	5810	1.57	47.1	nd	2.14	nd	nd	<MDL	nd	10.5
I10	19	5300	0.45	1.75	36.20	nd	nd	11.9	2.85	6100	4.14	57.5	nd	2.68	nd	nd	0.8	nd	13.3
I4	18	1570	0.31	1.42	3.36	nd	nd	9.5	0.49	3650	2.19	16.4	0.004	0.99	nd	nd	nd	nd	6.4
28-m Stations																			
I33	30	3730	nd	1.83	22.20	nd	nd	7.2	6.57	5550	2.70	54.5	0.015	2.49	nd	nd	nd	0.7	13.8
I30	28	5250	nd	1.66	31.50	nd	0.07	10.3	7.01	6260	1.89	57.0	0.003	3.36	nd	nd	nd	0.4	16.1
I27	28	5200	nd	1.32	30.00	nd	nd	9.6	6.68	6070	1.67	56.0	0.004	3.05	nd	nd	nd	0.4	15.2
I22	28	4500	nd	1.53	28.10	nd	0.06	9.2	6.55	5470	1.95	48.0	0.007	3.07	nd	nd	nd	0.3	13.0
I14*	28	7430	nd	1.52	40.10	nd	nd	11.5	8.01	7660	1.73	73.8	0.003	3.92	nd	nd	nd	0.5	18.7
I16*	28	3910	nd	1.57	20.40	nd	nd	7.5	5.44	5070	1.22	50.1	nd	1.97	nd	nd	nd	0.3	11.9
I15*	31	2480	nd	2.15	8.47	nd	nd	8.6	4.64	4510	1.82	26.9	<MDL	1.36	nd	nd	nd	0.4	8.4
I12*	28	3130	nd	1.59	17.60	nd	nd	8.0	5.51	4980	1.34	39.3	nd	1.70	nd	nd	nd	0.4	10.8
I9	29	7040	0.48	1.48	37.20	nd	nd	14.5	3.38	7180	5.01	67.8	0.004	4.07	nd	nd	nd	0.3	18.2
I6	26	677	0.35	5.41	1.99	nd	nd	4.9	nd	1530	1.58	8.3	0.005	0.63	nd	0.29	nd	nd	2.8
I2	32	943	0.31	0.60	2.28	nd	nd	6.5	nd	1070	1.28	6.5	0.004	0.76	nd	nd	nd	nd	2.3
I3	27	785	nd	1.25	1.96	nd	nd	6.4	nd	1420	1.29	5.8	nd	0.63	nd	0.16	nd	nd	2.2
38-m Stations																			
I29	38	5520	nd	2.08	31.50	nd	0.08	11.5	7.91	7820	2.71	57.6	0.007	4.09	nd	nd	nd	0.6	17.1
I21	41	1220	nd	7.64	2.01	0.05	0.06	11.3	0.66	7730	3.21	12.6	nd	0.88	nd	nd	nd	0.4	7.0
I13	38	1130	nd	6.36	2.87	nd	nd	9.8	3.85	5950	2.59	14.2	nd	0.83	nd	nd	nd	0.3	5.5
I8	36	1220	0.58	2.27	2.95	nd	0.14	12.0	nd	7700	3.89	14.9	0.004	0.94	nd	nd	nd	nd	6.2
55-m Stations																			
I28	55	5770	0.34	2.62	21.90	0.10	0.10	9.5	4.90	6830	5.22	50.0	0.021	4.80	nd	nd	nd	0.7	15.9
I20	55	1400	nd	2.90	2.77	0.04	nd	4.6	0.63	4790	1.55	16.7	nd	0.84	nd	nd	nd	nd	5.8
I7	52	1270	0.49	7.60	3.13	nd	nd	9.9	nd	4100	2.64	16.0	nd	0.74	nd	nd	nd	nd	4.4
I1	60	2960	0.46	1.18	12.60	0.02	0.06	8.9	1.20	3760	3.40	39.7	0.005	2.67	nd	nd	nd	nd	8.4
Detection Rate (%)		100	33	100	100	15	30	100	81	100	100	100	59	100	0	7	4	59	100
	ERL	na	na	8.2	na	na	1.2	81	34	na	46.7	na	0.15	20.9	na	1	na	na	150
	ERM	na	na	70	na	na	9.6	370	270	na	218	na	0.71	51.6	na	3.7	na	na	410

na = not available; nd = not detected; <MDL = Average of lab duplicates below MDL (see City of San Diego 2011)

Appendix C.8

Concentrations of tDDT, HCB, and tPCB detected at each SBOO benthic station during the January and July 2010 surveys. * = nearfield stations; ERL = Effects Range Low threshold value; ERM = Effects Range Median threshold value.

	January				July				
	Depth (m)	tDDT (ppt)	HCB (ppt)	tPCB (ppt)		Depth (m)	tDDT (ppt)	HCB (ppt)	tPCB (ppt)
19-m Stations					*19-m Stations*				
I35	19	nd	nd	nd	I35	19	nd	nd	nd
I34	19	nd	nd	nd	I34	19	nd	nd	nd
I31	19	nd	nd	nd	I31	19	nd	nd	nd
I23	21	85	nd	nd	I23	21	nd	nd	nd
I18	19	nd	62	nd	I18	19	nd	nd	nd
I10	19	nd	nd	nd	I10	19	nd	nd	nd
I4	18	nd	nd	nd	I4	18	nd	nd	nd
28-m Stations					*28-m Stations*				
I33	30	nd	nd	nd	I33	30	nd	nd	nd
I30	28	nd	100	nd	I30	28	nd	nd	nd
I27	28	170	nd	nd	I27	28	nd	nd	nd
I22	28	47	nd	nd	I22	28	nd	nd	nd
I14*	28	130	220	nd	I14*	28	nd	nd	nd
I16*	28	110	nd	nd	I16*	28	nd	nd	nd
I15*	31	nd	97	nd	I15*	31	nd	nd	nd
I12*	28	91	140	nd	I12*	28	nd	nd	nd
I9	29	nd	42	nd	I9	29	nd	nd	nd
I6	26	76	40	nd	I6	26	nd	nd	nd
I2	32	nd	130	nd	I2	32	nd	nd	nd
I3	27	nd	64	nd	I3	27	nd	nd	nd
38-m Stations					*38-m Stations*				
I29	38	1100	110	nd	I29	38	1100	nd	nd
I21	41	110	nd	nd	I21	41	nd	nd	nd
I13	38	nd	nd	nd	I13	38	nd	nd	nd
I8	36	nd	nd	nd	I8	36	nd	nd	nd
55-m Stations					*55-m Stations*				
I28	55	680	98	290	I28	55	630	nd	74
I20	55	nd	nd	nd	I20	55	nd	nd	nd
I7	52	80	nd	nd	I7	52	nd	nd	nd
I1	60	58	nd	nd	I1	60	nd	nd	nd
	Detection Rate (%)	44	41	4		Detection Rate (%)	7	0	4
	ERL	1580	na	na		ERL	1580	na	na
	ERM	46,100	na	na		ERM	46,100	na	na

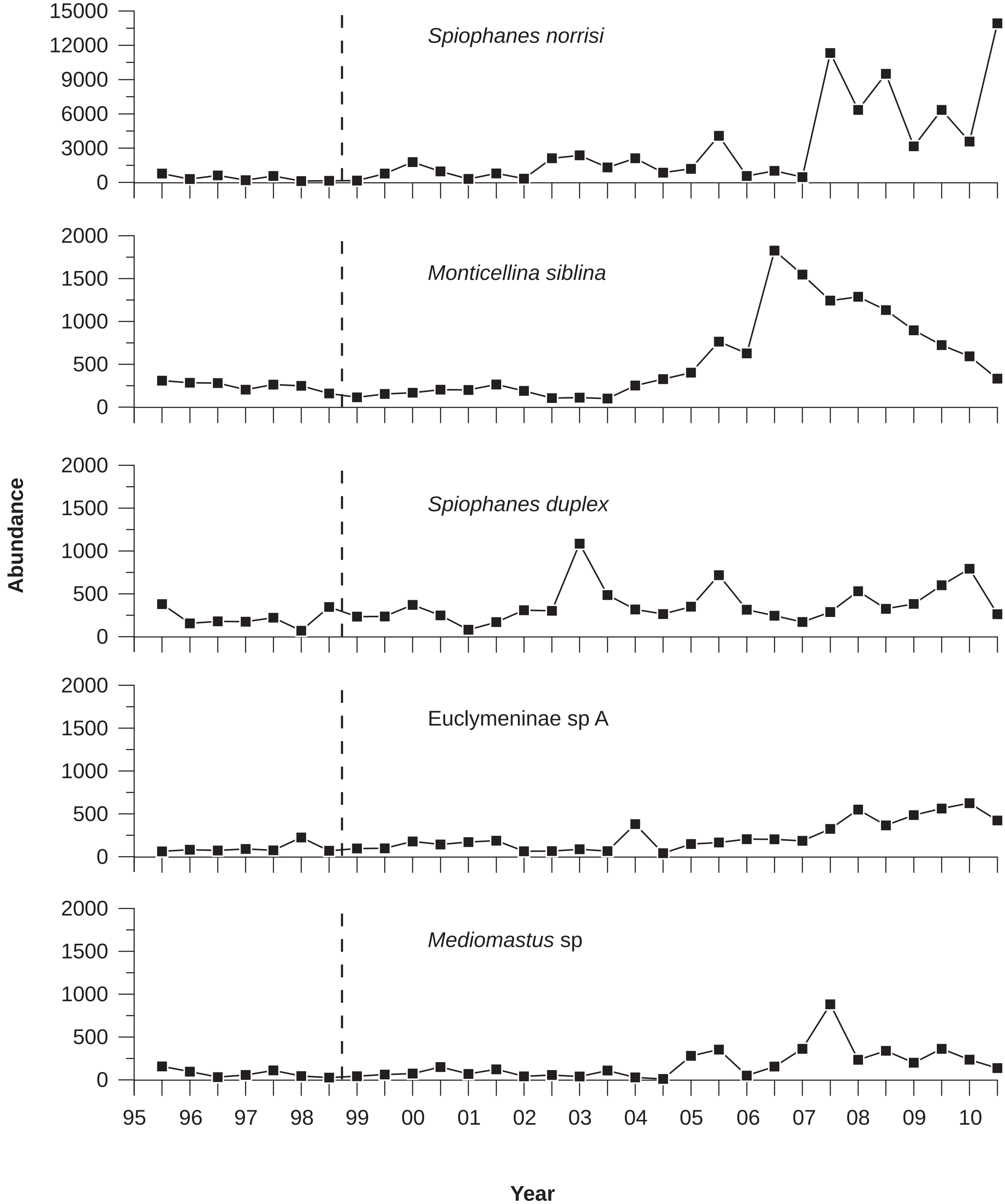
na = not available; nd = not detected

Appendix D

Supporting Data

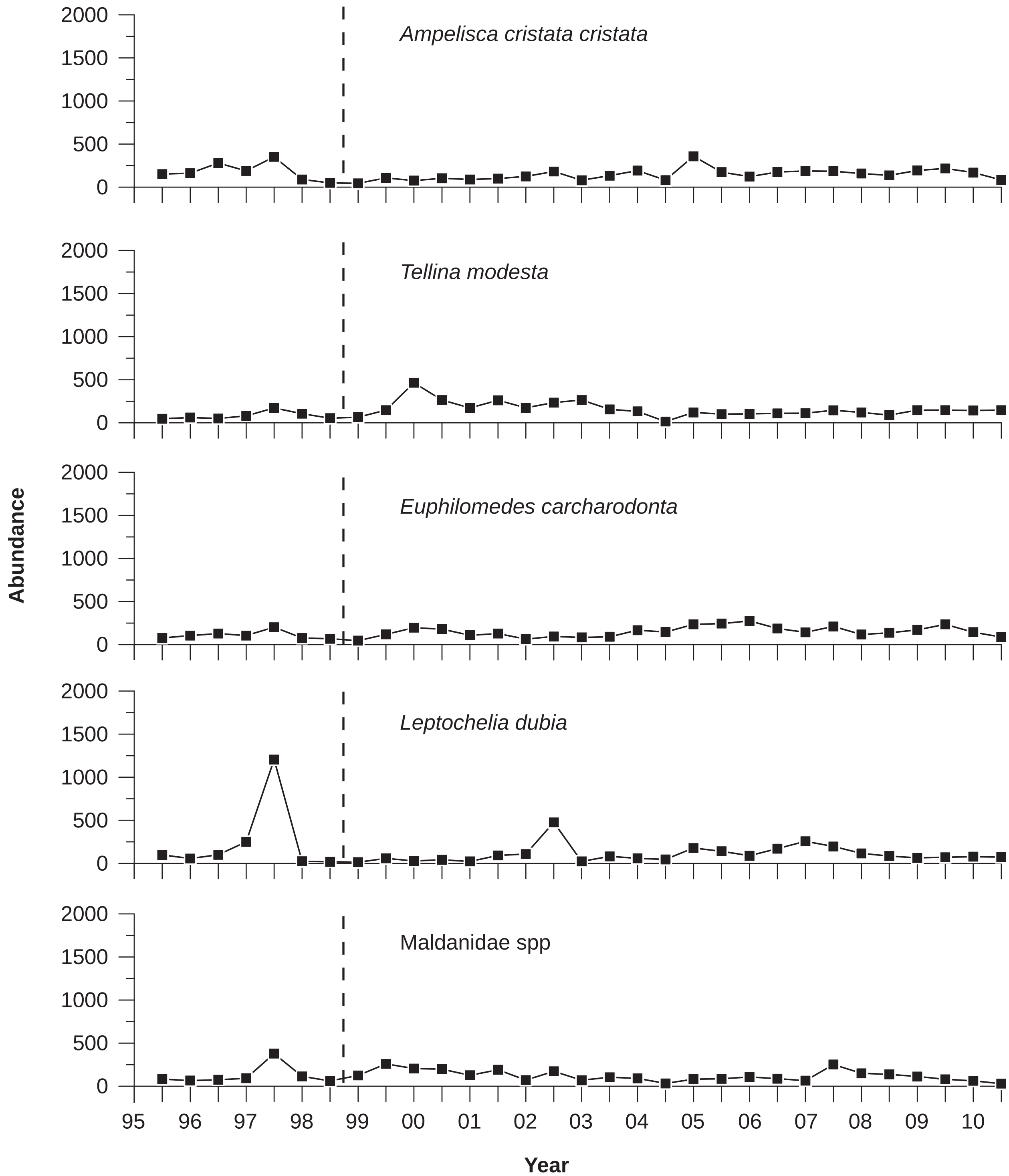
2010 SBOO Stations

Macrobenthic Communities



Appendix D.1

Total abundance per survey for each of the 10 most abundant species (taxa) at the SBOO benthic stations from 1995 to 2010; note expanded scale for *Spiophanes norrisi.* Dashed line indicates onset of wastewater discharge.



Appendix D.1 *continued*

Appendix D.2

Summary of taxa that distinguish between cluster groups according to SIMPER analysis. Shown are the five taxa with the greatest percent contribution to overall average Bray-Curtis dissimilarity between each group.

Species/Taxa	Average Dissimilarity/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups A & B			
Ophiuroconis bispinosa	2.6	1.6	1.6
Jasmineira sp B	2.5	1.4	2.9
Notomastus latericeus	1.5	1.3	4.2
Mooreonuphis sp SD1	1.6	1.3	5.5
Dendraster terminalis	2.7	1.3	6.8
Groups A & C			
Dendraster terminalis	1.4	1.9	1.9
Ophiuroconis bispinosa	1.9	1.5	3.4
Jasmineira sp B	2.3	1.4	4.8
Scoloplos armiger Cmplx	1.5	1.4	6.2
Mooreonuphis sp SD1	1.6	1.3	7.4
Groups A & D			
Ophiuroconis bispinosa	5.3	1.6	1.6
Eurydice caudata	2.0	1.4	3.0
Jasmineira sp B	2.5	1.2	4.2
Mooreonuphis sp SD1	1.5	1.2	5.4
Lirobarleeia kelseyi	2.3	1.0	6.4
Groups A & E			
Tellina modesta	2.4	1.2	1.2
Eurydice caudata	2.2	1.1	2.3
Ophiuroconis bispinosa	2.7	1.1	3.4
Mooreonuphis sp SD1	1.5	1.0	4.4
Jasmineira sp B	2.3	0.9	5.3
Groups A & F			
Axinopsida serricata	3.3	1.4	1.4
Pista estevanica	1.2	1.3	2.7
Aricidea (*Acmira*) *simplex*	2.3	1.3	4.0
Myriochele gracilis	1.9	1.0	5.0
Eurydice caudata	1.9	1.0	6.0
Groups B & C			
Glycera oxycephala	2.1	1.6	1.6
Notomastus latericeus	1.4	1.5	3.1
Solamen columbianum	1.4	1.3	4.4
Spio maculata	1.8	1.3	5.6
Amphiodia urtica	1.3	1.2	6.8
Groups B & D			
Glycera oxycephala	2.4	1.5	1.5

Appendix D.2 *continued*

Species/Taxa	Average Dissimilarity/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups B & D			
Lumbrinerides platypygos	1.8	1.3	2.9
Dendraster terminalis	2.8	1.3	4.2
Amphiodia urtica	1.3	1.2	5.4
Notomastus latericeus	1.4	1.2	6.6
Groups B & E			
Glycera oxycephala	2.1	1.2	1.2
Spiophanes berkeleyorum	1.9	1.1	2.3
Euclymeninae sp A	2.5	1.0	3.3
Lumbrinerides platypygos	1.7	1.0	4.3
Dendraster terminalis	2.7	1.0	5.2
Groups B & F			
Aricidea (*Acmira*) *simplex*	3.2	1.5	1.5
Axinopsida serricata	3.4	1.3	2.8
Pista estevanica	1.1	1.2	4.0
Photis californica	2.4	1.1	5.0
Myriochele gracilis	1.9	1.0	6.0
Groups C & D			
Dendraster terminalis	1.3	1.6	1.6
Spio maculata	3.3	1.3	2.9
Scoloplos armiger Cmplx	1.4	1.1	4.0
Solamen columbianum	1.7	1.1	5.1
Typosyllis sp SD2	1.9	1.1	6.2
Groups C & E			
Tellina modesta	2.4	1.2	1.2
Dendraster terminalis	1.4	1.2	2.4
Spiophanes berkeleyorum	2.0	1.1	3.5
Euclymeninae sp A	2.6	1.0	4.5
Spio maculata	3.0	0.9	5.4
Groups C & F			
Aricidea (*Acmira*) *simplex*	3.1	1.4	1.4
Pista estevanica	1.3	1.4	2.8
Axinopsida serricata	3.4	1.3	4.1
Dendraster terminalis	1.3	1.0	5.1
Photis californica	2.2	1.0	6.1
Groups D & E			
Mooreonuphis nebulosa	1.4	0.9	0.9
Tellina modesta	1.5	0.9	1.8
Euphilomedes carcharodonta	1.6	0.9	2.6

Appendix D.2 *continued*

Species/Taxa	Average Dissimilarity/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups D & E			
Euclymeninae sp A	1.8	0.8	3.5
Ampelisca brevisimulata	2.3	0.8	4.3
Groups D & F			
Aricidea (*Acmira*) *simplex*	3.2	1.4	1.4
Pista estevanica	1.3	1.3	2.8
Axinopsida serricata	3.3	1.3	4.0
Photis californica	2.4	1.0	5.1
Myriochele gracilis	1.9	1.0	6.0
Groups E & F			
Aricidea (*Acmira*) *simplex*	3.2	1.4	1.4
Axinopsida serricata	2.5	1.2	2.5
Pista estevanica	1.1	1.0	3.5
Photis californica	2.2	0.9	4.4
Myriochele gracilis	2.0	0.9	5.3

Appendix E

Supporting Data

2010 SBOO Stations

Demersal Fishes and Megabenthic Invertebrates

Appendix E.1

Summary of demersal fish species captured during 2010 at SBOO trawl stations. Data are number of fish (*n*), biomass (BM; kg, wet weight), minimum, maximum, and mean length (cm, standard length). Taxonomic arrangement and scientific names are of Eschmeyer and Herald (1998) and Allen (2005).

					Length	
Taxon/Species	**Common Name**	***n***	**BM**	**Min**	**Max**	**Mean**
SQUATINIFORMES						
Squatinidae						
Squatina californica	Pacific angel shark	2	23.2	38	107	73
TORPEDINIFORMES						
Torpedinidae						
Torpedo californica	Pacific electric ray	1	10.0	70	70	70
RAJIFORMES						
Rhinobatidae						
Rhinobatos productus	shovelnose guitarfish	8	3.3	29	64	44
Platyrhynidae						
Platyrhinoidis triseriata	thornback	8	2.0	20	42	28
Rajidae						
Raja inornata	California skate	4	0.7	23	42	28
MYLIOBATIFROMES						
Urolophidae						
Urobatis halleri	round stingray	8	3.1	17	39	27
Gymnuridae						
Gymnura marmorata	California butterfly ray	2	2.2	21	32	27
CLUPERIFORMES						
Engraulidae						
Engraulis mordax	northern anchovy	16	0.5	6	10	9
AULOPIFORMES						
Synodontidae						
Synodus lucioceps	California lizardfish	1380	19.4	7	24	12
OPHIDIIFORMES						
Ophidiidae						
Chilara taylori	spotted cuskeel	4	0.3	11	16	14
Ophidion scrippsae	basketweave cuskeel	6	0.2	17	19	18
BATRACHOIDIFORMES						
Batrachoididae						
Porichthys notatus	plainfin midshipman	17	1.2	4	25	9
Porichthys myriaster	specklefin midshipman	14	0.3	6	23	10
SYNGNATHIFORMIES						
Syngnathidae						
Syngnathus californiensis	kelp pipefish	1	0.1	23	23	23
Syngnathus exilis	barcheek pipefish	2	0.2	12	13	13
SCORPAENIFORMES						
Scorpaenidae						
Scorpaena guttata	California scorpionfish	16	6.2	10	28	20
Sebastes auriculatus	brown rockfish	1	0.1	6	6	6
Sebastes miniatus	vermilion rockfish	6	0.4	4	6	4
Sebastes saxicola	stripetail rockfish	5	0.3	3	4	4

Appendix E.1 *continued*

Taxon/Species			Common Name	*n*	BM	Length Min	Length Max	Length Mean
	Hexagrammidae							
		Zaniolepis latipinnis	longspine combfish	67	2.1	11	18	14
	Cottidae							
		Chitonotus pugetensis	roughback sculpin	196	3.2	5	13	9
		Icelinus quadriseriatus	yellowchin sculpin	412	2.4	4	8	7
	Agonidae							
		Odontopyxis trispinosa	pygmy poacher	4	0.4	6	8	7
PERCIFORMES								
	Serranidae							
		Paralabrax clathratus	kelp bass	4	0.1	6	9	8
	Malacanthidae							
		Caulolatilus princeps	ocean whitefish	8	0.4	4	6	5
	Sciaenidae							
		Genyonemus lineatus	white croaker	273	16.0	9	22	14
		Seriphus politus	queenfish	43	1.6	8	15	12
	Embiotocidae							
		Brachyistius frenatus	kelp perch	1	0.1	8	8	8
		Cymatogaster aggregata	shiner perch	25	1.1	8	11	10
		Zalembius rosaceus	pink seaperch	5	0.2	9	11	10
	Chaenopsidae							
		Neoclinus blanchardii	sarcastic fringehead	3	0.3	3	14	7
	Stromateidae							
		Peprilus simillimus	Pacific pompano	183	6.2	8	13	11
PLEURONECTIFORMES								
	Paralichthyidae							
		Citharichthys stigmaeus	speckled sanddab	3198	25.8	3	13	7
		Citharichthys xanthostigma	longfin sanddab	90	5.2	5	20	12
		Hippoglossina stomata	bigmouth sole	1	0.1	14	14	14
		Paralichthys californicus	California halibut	9	4.9	22	42	30
		Xystreurys liolepis	fantail sole	6	1.4	9	28	18
	Pleuronectidae							
		Parophrys vetulus	English sole	346	8.9	9	24	12
		Pleuronichthys decurrens	curlfin sole	2	0.2	13	14	14
		Pleuronichthys guttulatus	diamond turbot	3	0.5	13	20	16
		Pleuronichthys ritteri	spotted turbot	4	0.6	13	19	16
		Pleuronichthys verticalis	hornyhead turbot	89	6.6	4	23	12
	Cynoglossidae							
		Symphurus atricaudus	California tonguefish	97	2.6	5	16	10

Appendix E.2

Summary of total abundance by species and station for demersal fishes at the SBOO trawl stations during 2010.

Name	January 2010							Species Abundance by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Speckled sanddab	97	92	8	38	14	45	14	308
White croaker	8	16	25	52	92	15	17	225
California lizardfish	11	38	5	4	10	7	49	124
Queenfish	1	2		16	10	2	8	39
California tonguefish		2	6	16	3	3	7	37
Shiner perch	3	1	13	2	2	1	1	23
Northern anchovy			1		10	2	2	15
Pacific pompano		2			11			13
Specklefin midshipman						1	12	13
Ocean whitefish	3			2		2	1	8
Thornback		1		1	1	1	4	8
Hornyhead turbot	1	2				2	2	7
Round stingray				1		2	4	7
Plainfin midshipman		1			3	1	1	6
Kelp bass			4					4
Pink seaperch				4				4
Spotted cuskeel				2	1	1		4
California butterfly ray				2				2
California halibut				1			1	2
Diamond turbot	2							2
Fantail sole		1		1				2
Sarcastic fringehead	1	1						2
Shovelnose guitarfish						1	1	2
Basketweave cuskeel							1	1
California skate					1			1
Pacific angel shark							1	1
Kelp perch							1	1
Pygmy poacher				1				1
Quarter Total	127	159	62	143	158	86	127	862

Appendix E.2 *continued*

Name	April 2010							Species Abundance by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Speckled sanddab	109	100	42	52	51	87	16	457
Pacific pompano				165			3	168
California lizardfish	1	29	11	3	6	5		55
White croaker			2	30	1		15	48
Roughback sculpin	3	4	7		7	10		31
Longspine combfish		4	13	1	1	9	1	29
Hornyhead turbot	1	5	2	6	3	1	6	24
English sole		2	4	9	2	3	2	22
California tonguefish		1	1	3	2		7	14
Yellowchin sculpin			7	3	1			11
Longfin sanddab		1	2	1	2			6
Shovelnose guitarfish	1		1	2		1	1	6
Basketweave cuskeel				5				5
California scorpionfish					1	1	3	5
Stripetail rockfish			3	1	1			5
Vermilion rockfish	3	1				1		5
California halibut					1	1	2	4
Queenfish				4				4
California skate						2		2
Shiner perch							2	2
Curlfin sole	1							1
Diamond turbot	1							1
Northern anchovy							1	1
Pacific angel shark		1						1
Plainfin midshipman						1		1
Pygmy poacher						1		1
Round stingray							1	1
Sarcastic fringehead	1							1
Specklefin midshipman							1	1
Spotted turbot				1				1
Quarter Total	121	148	95	286	79	123	61	913

Appendix E.2 *continued*

Name	July 2010							Species Abundance by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Speckled sanddab	346	158	193	326	242	140	200	1605
California lizardfish	69	208	86	53	152	54	15	637
Yellowchin sculpin		18	77	33	30	69	52	279
Roughback sculpin	10	23	14	7	12	28	7	101
Longfin sanddab		7	15	3	5	7	17	54
Hornyhead turbot	5	4	5	7	2	2	3	28
English sole	1	2		2	1	10	4	20
California tonguefish		2	1	1	6		3	13
Longspine combfish					2		4	6
California halibut					1		2	3
California scorpionfish	1		1				1	3
Fantail sole		1					1	2
Spotted turbot	2							2
Barcheek pipefish						1		1
Brown rockfish		1						1
California skate							1	1
Pacific electric ray	1							1
Pink seaperch							1	1
Plainfin midshipman		1						1
Vermilion rockfish						1		1
Quarter Total	435	425	392	432	453	312	311	2760

Appendix E.2 *continued*

Name	SD15	SD16	SD17	SD18	SD19	SD20	SD21	Species Abundance by Survey
	October 2010							
Speckled sanddab	168	150	123	136	85	58	108	828
California lizardfish	119	154	119	60	29	56	27	564
English sole		95	4	5	14	75	111	304
Yellowchin sculpin		9	70	11	2	2	28	122
Roughback sculpin	3	14	32		1	3	11	64
California tonguefish		3	1		8	2	19	33
Longspine combfish		6	4		1		21	32
Hornyhead turbot		3	15	2	6		4	30
Longfin sanddab		2	10	2	5	1	10	30
Plainfin midshipman		1			4	2	2	9
California scorpionfish	1						7	8
Fantail sole		2						2
Pacific pompano					2			2
Pygmy poacher		1	1					2
Barcheek pipefish					1			1
Bigmouth sole				1				1
Curlfin sole		1						1
Kelp pipefish	1							1
Spotted turbot	1							1
Quarter Total	293	441	379	217	158	199	348	2035
Annual Total	**976**	**1173**	**928**	**1078**	**848**	**720**	**847**	**6570**

Appendix E.3

Summary of biomass (kg) by species and station for demersal fishes at the SBOO trawl stations during 2010.

	January 2010							
Name	SD15	SD16	SD17	SD18	SD19	SD20	SD21	Species Biomass by Survey
Pacific angel shark							23.0	23.0
White croaker	0.6	0.7	1.5	3.4	5.0	0.9	1.0	13.1
Round stingray				0.6		0.4	1.9	2.9
Speckled sanddab	0.9	0.9	0.1	0.2	0.1	0.5	0.1	2.8
California butterfly ray				2.2				2.2
California lizardfish	0.3	0.5	0.2	0.1	0.2	0.1	0.7	2.1
Thornback		0.3		0.6	0.1	0.2	0.8	2.0
Queenfish	0.1	0.1		0.7	0.4	0.1	0.1	1.5
California halibut				0.6			0.6	1.2
Fantail sole		0.7		0.3				1.0
Shiner perch	0.1	0.1	0.4	0.1	0.1	0.1	0.1	1.0
California tonguefish		0.1	0.2	0.3	0.1	0.1	0.1	0.9
Hornyhead turbot	0.4	0.2				0.1	0.1	0.8
Shovelnose guitarfish						0.4	0.2	0.6
Plainfin midshipman		0.1			0.2	0.1	0.1	0.5
Diamond turbot	0.4							0.4
Northern anchovy			0.1		0.1	0.1	0.1	0.4
Ocean whitefish	0.1			0.1		0.1	0.1	0.4
Pacific pompano		0.1			0.2			0.3
Spotted cuskeel				0.1	0.1	0.1		0.3
Sarcastic fringehead	0.1	0.1						0.2
Specklefin midshipman						0.1	0.1	0.2
Basketweave cuskeel							0.1	0.1
Kelp perch							0.1	0.1
California skate					0.1			0.1
Kelp bass			0.1					0.1
Pink seaperch				0.1				0.1
Pygmy poacher				0.1				0.1
Quarter Total	3.0	3.9	2.6	9.5	6.7	3.4	29.3	58.4

Appendix E.3 *continued*

Name	SD15	SD16	SD17	SD18	SD19	SD20	SD21	Species Biomass by Survey
	April 2010							
Pacific pompano				5.7			0.1	5.8
Speckled sanddab	0.1	0.7	0.4	0.5	0.4	0.7	0.2	3.0
White croaker			0.1	2.3	0.1		0.4	2.9
Shovelnose guitarfish	1.0		0.5	0.9		0.1	0.2	2.7
Hornyhead turbot	0.1	0.1	0.2	0.8	0.1	0.1	1.0	2.4
California halibut					0.4	0.4	1.5	2.3
California scorpionfish					0.5	0.7	1.1	2.3
English sole		0.1	0.3	0.7	0.1	0.1	0.2	1.5
Longspine combfish		0.1	0.4	0.1	0.1	0.3	0.1	1.1
California lizardfish	0.1	0.3	0.2	0.1	0.1	0.1		0.9
Roughback sculpin	0.1	0.2	0.1		0.1	0.1		0.6
California skate						0.5		0.5
California tonguefish		0.1	0.1	0.1	0.1		0.1	0.5
Longfin sanddab		0.1	0.1	0.1	0.1			0.4
Stripetail rockfish			0.1	0.1	0.1			0.3
Vermilion rockfish	0.1	0.1				0.1		0.3
Yellowchin sculpin			0.1	0.1	0.1			0.3
Pacific angel shark		0.2						0.2
Round stingray							0.2	0.2
Basketweave cuskeel				0.1				0.1
Curlfin sole	0.1							0.1
Diamond turbot	0.1							0.1
Northern anchovy							0.1	0.1
Plainfin midshipman						0.1		0.1
Pygmy poacher						0.1		0.1
Queenfish				0.1				0.1
Sarcastic fringehead	0.1							0.1
Shiner perch							0.1	0.1
Specklefin midshipman							0.1	0.1
Spotted turbot				0.1				0.1
Quarter Total	1.8	2.0	2.6	11.8	2.3	3.4	5.4	29.3

Appendix E.3 *continued*

Name	July 2010							Species Biomass by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Speckled sanddab	2.5	1.7	1.5	2.7	1.5	1.2	1.1	12.2
Pacific electric ray	10.0							10.0
California lizardfish	0.7	2.0	0.8	0.5	1.4	0.7	0.1	6.2
Longfin sanddab		0.5	0.5	0.1	0.6	0.5	0.6	2.8
Hornyhead turbot	0.2	0.2	0.4	0.7	0.2	0.2	0.3	2.2
California halibut					0.7		0.7	1.4
Roughback sculpin	0.1	0.2	0.1	0.1	0.2	0.6	0.1	1.4
Yellowchin sculpin		0.1	0.3	0.1	0.2	0.4	0.3	1.4
English sole	0.1	0.1		0.1	0.1	0.7	0.1	1.2
California scorpionfish	0.1		0.6				0.1	0.8
California tonguefish		0.1	0.1	0.1	0.1		0.1	0.5
Spotted turbot	0.3							0.3
Fantail sole		0.1					0.1	0.2
Longspine combfish					0.1		0.1	0.2
Barcheek pipefish						0.1		0.1
Brown rockfish		0.1						0.1
California skate							0.1	0.1
Pink seaperch							0.1	0.1
Plainfin midshipman		0.1						0.1
Vermilion rockfish						0.1		0.1
Quarter Total	14.0	5.2	4.3	4.4	5.1	4.5	3.9	41.4

Appendix E.3 *continued*

Name	October 2010							Species Biomass by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
California lizardfish	1.5	3.3	2.0	1.0	0.5	1.5	0.4	10.2
Speckled sanddab	1.6	1.1	1.0	1.0	1.4	0.9	0.8	7.8
English sole		3.3	0.1	0.2	0.5	2.0	0.1	6.2
California scorpionfish	0.4						2.7	3.1
Longfin sanddab		0.3	0.6	0.1	0.5	0.1	0.4	2.0
Hornyhead turbot		0.1	0.1	0.2	0.3		0.5	1.2
Roughback sculpin	0.1	0.2	0.5		0.1	0.1	0.2	1.2
Longspine combfish		0.1	0.1		0.1		0.5	0.8
California tonguefish		0.1	0.1		0.2	0.1	0.2	0.7
Yellowchin sculpin		0.1	0.2	0.1	0.1	0.1	0.1	0.7
Plainfin midshipman		0.1			0.2	0.1	0.1	0.5
Fantail sole		0.2						0.2
Pygmy poacher		0.1	0.1					0.2
Spotted turbot	0.2							0.2
Barcheek pipefish					0.1			0.1
Bigmouth sole				0.1				0.1
Curlfin sole		0.1						0.1
Kelp pipefish	0.1							0.1
Pacific pompano					0.1			0.1
Quarter Total	3.9	9.1	4.8	2.7	4.1	4.9	6.0	35.5
Annual Total	**22.7**	**20.2**	**14.3**	**28.4**	**18.2**	**16.2**	**44.6**	**164.6**

Appendix E.4

Summary of the demersal fish species that distinguish between cluster groups according to SIMPER analysis. Shown are the five species with the greatest percent contribution to overall averge Bray-Curtis dissimilarity between each group.

Species	Average Dissimilarity / Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups B & A			
California lizardfish	2.5	33.7	33.7
Speckled sanddab	2.1	16.3	50.0
Yellowchin sculpin	1.4	12.2	62.2
Roughback sculpin	1.3	7.0	69.2
Longfin sanddab	1.5	5.4	74.6
Groups C & A			
California lizardfish	6.1	46.5	46.5
Speckled sanddab	1.9	9.5	56.0
Yellowchin sculpin	1.0	8.9	64.9
Longfin sanddab	1.7	6.7	71.6
Roughback sculpin	1.0	4.1	75.6
Groups C & B			
Yellowchin sculpin	1.6	17.8	17.8
California lizardfish	1.3	15.0	32.9
Speckled sanddab	1.3	12.0	44.8
Roughback sculpin	1.6	10.5	55.3
Longfin sanddab	1.4	8.6	63.9
Groups C & D			
Longfin sanddab	1.6	19.2	19.2
Speckled sanddab	1.4	14.4	33.6
California tonguefish	1.5	7.7	41.3
English sole	1.7	6.7	48.0
California lizardfish	1.4	6.4	54.4
Groups C & E			
Speckled sanddab	2.5	34.6	34.6
California lizardfish	1.1	10.9	45.5
Longfin sanddab	1.1	8.5	54.0
Hornyhead turbot	1.3	5.7	59.7
English sole	0.9	5.2	65.0

Appendix E.4 *continued*

Species	Average Dissimilarity / Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups D & A			
California lizardfish	5.1	44.3	44.3
Yellowchin sculpin	1.1	8.8	53.1
Longfin sanddab	1.2	8.5	61.7
California tonguefish	1.7	4.1	65.7
Roughback sculpin	1.0	4.0	69.7
Groups D & B			
Speckled sanddab	1.7	17.0	17.0
Yellowchin sculpin	1.4	14.2	31.2
California lizardfish	1.2	12.0	43.2
Longfin sanddab	1.2	9.7	52.9
Roughback sculpin	1.5	9.0	61.9
Groups D & E			
Speckled sanddab	1.9	18.0	18.0
Longfin sanddab	1.3	14.4	32.4
California lizardfish	1.1	9.2	41.6
California tonguefish	1.5	6.8	48.5
English sole	1.4	6.0	54.5
Groups E & A			
California lizardfish	3.6	42.7	42.7
Speckled sanddab	2.3	11.8	54.4
Yellowchin sculpin	1.0	8.8	63.2
Longfin sanddab	1.3	5.4	68.7
Roughback sculpin	1.0	4.0	72.6
Groups E & B			
Speckled sanddab	2.7	27.6	27.6
Yellowchin sculpin	1.6	14.1	41.7
California lizardfish	1.4	11.9	53.6
Roughback sculpin	1.7	8.8	62.4
Longfin sanddab	1.4	6.3	68.7

Appendix E.5

List of megabenthic invertebrate taxa captured during 2010 at SBOO trawl stations. Data are number of individuals (*n*). Taxonomic arrangement from SCAMIT 2008.

Taxon/ Species					*n*
CNIDARIA					
	ANTHOZOA				
		PENNATULACEA			
			Virgulariidae		
				Acanthoptilum sp	1
MOLLUSCA					
	GASTROPODA				
			Calliostomatidae		
				Calliostoma canaliculatum	1
			Turbinidae		
				Megastraea turbanica	1
		HYPSOGASTROPODA			
			Naticidae		
				Glossaulax reclusianus	2
			Bursidae		
				Crossata californica	5
			Velutinidae		
				Lamellaria diegoensis	1
			Buccinidae		
				Kelletia kelletii	18
			Nassariidae		
				Caesia perpinguis	1
			Muricidae		
				Forreria belcheri	2
				Pteropurpura festiva	3
			Turridae		
				Megasurcula carpenteriana	2
				Antiplanes catalinae	1
				Crassispira semiinflata	1
		OPISTHOBRANCHIA			
			Philinidae		
				Philine auriformis	3
			Pleurobranchidae		
				Pleurobranchaea californica	2
			Onchidorididae		
				Acanthodoris brunnea	13
				Acanthodoris rhodoceras	5
			Polyceridae		
				Triopha maculata	1
			Tritoniidae		
				Tritonia diomedea	1
			Dendronotidae		
				Dendronotus iris	49
			Flabellinidae		
				Flabellina iodinea	14
	CEPHALOPODA				
		TEUTHIDA			
			Loliginidae		
				Doryteuthis opalescens	163
		OCTOPODA			
			Octopodidae		
				Octopus rubescens	50

Appendix E.5 *continued*

Taxon/ Species					*n*
ANNELIDA					
	POLYCHAETA				
		ACICULATA			
			Aphroditidae		
				Aphrodita armifera	2
				Aphrodita refulgida	2
	HIRUDINEA				2
ARTHROPODA					
	MALACOSTRACA				
		STOMATOPODA			
			Hemisquillidae		
				Hemisquilla californiensis	4
		ISOPODA			
			Cymothoidae		
				Elthusa vulgaris	24
		DECAPODA			
			Penaeidae		
				Farfantepenaeus californiensis	19
			Sicyoniidae		
				Sicyonia disedwardsi	1
				Sicyonia ingentis	39
				Sicyonia penicillata	6
			Alpheidae		
				Alpheus clamator	1
			Hippolytidae		
				Heptacarpus palpator	3
				Heptacarpus stimpsoni	11
				Spirontocaris prionota	1
			Pandalidae		
				Pandalus danae	11
			Crangonidae		
				Crangon alba	14
				Crangon nigromaculata	599
			Palinuridae		
				Panulirus interruptus	1
			Diogenidae		
				Paguristes bakeri	4
				Paguristes ulreyi	1
			Paguridae		
				Orthopagurus minimus	1
				Pagurus spilocarpus	5
			Calappidae		
				Platymera gaudichaudii	26
			Leucosiidae		
				Randallia ornata	11
			Epialtidae		
				Loxorhynchus grandis	3
				Scyra acutifrons	3
			Inachidae		
				Podochela hemphillii	3
			Inachoididae		
				Pyromaia tuberculata	34

Appendix E.5 *continued*

Taxon/ Species				*n*
		Parthenopidae		
			Heterocrypta occidentalis	29
		Cancridae		6
			Metacarcinus anthonyi	4
			Metacarcinus gracilis	39
			Romaleon antennarius	1
		Portunidae		
			Portunus xantusii	86
		Xanthidae		
			Paraxanthias taylori	1
		Pinnotheridae		
			Pinnixa franciscana	1
ECHINODERMATA				
ASTEROIDEA				
	PAXILLOSIDA			
		Luidiidae		
			Luidia armata	1
			Luidia foliolata	1
		Astropectinidae		
			Astropecten verrilli	268
	FORCIPULATIDA			
		Asteriidae		
			Pisaster brevispinus	18
OPHIUROIDEA				
	OPHIURIDA			
		Ophiotricidae		
			Ophiothrix spiculata	77
		Ophiocomidae		
			Ophiopteris papillosa	1
		Ophiuridae		
			Ophiura luetkenii	82
ECHINOIDEA				
	TEMNOPLEUROIDA			
		Toxopneustidae		
			Lytechinus pictus	11
	ECHINOIDA			
		Strongylocentrotidae		
			Strongylocentrotus franciscanus	3
	CLYPEASTEROIDA			
		Dendrasteridae		
			Dendraster terminalis	124

Appendix E.6

Summary of total abundance by species and station for megabenthic invertebrates at the SBOO trawl stations during 2010.

	January 2010							
Name	SD15	SD16	SD17	SD18	SD19	SD20	SD21	Species Abundance by Survey
Crangon nigromaculata	3	40	72	101	17	33	140	406
Portunus xantusii	6	5		31	8	5	30	85
Sicyonia ingentis	39							39
Ophiothrix spiculata	2	1		2			22	27
Farfantepenaeus californiensis	8		3	4	2	2		19
Astropecten verrilli	9	5	1		1			16
Metacarcinus gracilis		4	3	2	1	4	2	16
Pyromaia tuberculata	1	12		3				16
Pandalus danae		7		1				8
Randallia ornata			1	1	3	1	2	8
Lytechinus pictus			4	1			2	7
Dendraster terminalis	6							6
Cancridae					1		2	3
Elthusa vulgaris		1				2		3
Kelletia kelletii		3						3
Octopus rubescens	1	2						3
Scyra acutifrons		3						3
Strongylocentrotus franciscanus							3	3
Aphrodita armifera				2				2
Flabellina iodinea				1	1			2
Heptacarpus palpator					2			2
Heptacarpus stimpsoni					1		1	2
Heterocrypta occidentalis					1		1	2
Paguristes bakeri				2				2
Sicyonia penicillata				1	1			2
Acanthodoris brunnea			1					1
Alpheus clamator							1	1
Aphrodita refulgida							1	1
Glossaulax reclusianus			1					1
Hirudinea						1		1
Loxorhynchus grandis				1				1
Metacarcinus anthonyi				1				1
Ophiopteris papillosa							1	1
Orthopagurus minimus							1	1
Pagurus spilocarpus						1		1
Panulirus interruptus				1				1
Paraxanthias taylori							1	1
Pinnixa franciscana							1	1
Platymera gaudichaudii						1		1
Pleurobranchaea californica				1				1
Romaleon antennarius			1					1
Sicyonia disedwardsi						1		1
Spirontocaris prionota							1	1
Tritonia diomedea				1				1
Quarter Total	75	83	87	157	39	51	212	704

Appendix E.6 *continued*

Name	SD15	SD16	SD17	SD18	SD19	SD20	SD21	Species Abundance by Survey
	April 2010							
Crangon nigromaculata		50	14	62	14	4	31	175
Dendraster terminalis	20	30		2				52
Astropecten verrilli	12	10	7	1	2	1	1	34
Heptacarpus stimpsoni							8	8
Crangon alba	6	1						7
Metacarcinus gracilis					2	1	4	7
Platymera gaudichaudii	1	1	2	1		1		6
Pisaster brevispinus			1	1		1	2	5
Kelletia kelletii		1	1			1	1	4
Elthusa vulgaris	1	2						3
Hemisquilla californiensis			1		1	1		3
Acanthodoris brunnea				2				2
Cancridae							2	2
Randallia ornata		1					1	2
Sicyonia penicillata						1	1	2
Acanthoptilum sp	1							1
Aphrodita refulgida				1				1
Calliostoma canaliculatum	1							1
Crossata californica		1						1
Dendronotus iris							1	1
Doryteuthis opalescens				1				1
Forreria belcheri					1			1
Glossaulax reclusianus		1						1
Heptacarpus palpator							1	1
Hirudinea				1				1
Loxorhynchus grandis							1	1
Metacarcinus anthonyi							1	1
Portunus xantusii		1						1
Triopha maculata		1						1
Quarter Total	42	100	26	72	20	11	55	326

Appendix E.6 *continued*

Name	SD15	SD16	SD17	SD18	SD19	SD20	SD21	Species Abundance by Survey
	July 2010							
Astropecten verrilli	63	7	3	11	5	16	1	106
Dendronotus iris		15	3	3	6	18	1	46
Ophiothrix spiculata	1	40	1	1				43
Dendraster terminalis	23							23
Ophiura luetkenii			19	4				23
Crangon nigromaculata	1			4			9	14
Heterocrypta occidentalis			1	12			1	14
Pyromaia tuberculata		2	3	6			1	12
Elthusa vulgaris	1		1	2	5		1	10
Flabellina iodinea		2	1	1		3	2	9
Platymera gaudichaudii			1	3	3			7
Kelletia kelletii			2	2	1	1		6
Octopus rubescens		2			1	2	1	6
Metacarcinus gracilis		3				2		5
Pisaster brevispinus			2	1	2			5
Philine auriformis			1	1	1			3
Podochela hemphillii		2	1					3
Pteropurpura festiva			2	1				3
Acanthodoris brunnea				2				2
Lytechinus pictus	1		1					2
Megasurcula carpenteriana					1		1	2
Paguristes bakeri			2					2
Pagurus spilocarpus				1	1			2
Caesia perpinguis						1		1
Crassispira semiinflata				1				1
Forreria belcheri				1				1
Hemisquilla californiensis		1						1
Heptacarpus stimpsoni							1	1
Luidia foliolata				1				1
Paguristes ulreyi		1						1
Pleurobranchaea californica		1						1
Randallia ornata		1						1
Quarter Total	90	77	44	58	26	43	19	357

Appendix E.6 *continued*

Name	SD15	SD16	SD17	SD18	SD19	SD20	SD21	Species Abundance by Survey
	October 2010							
Doryteuthis opalescens			162					162
Astropecten verrilli	72	25	7	2	3	3		112
Ophiura luetkenii			27	31		1		59
Dendraster terminalis	39			4				43
Octopus rubescens			8		5	2	26	41
Heterocrypta occidentalis		2		10	1			13
Platymera gaudichaudii	2		7	2		1		12
Metacarcinus gracilis				1		7	3	11
Acanthodoris brunnea		1	1	5			1	8
Elthusa vulgaris		4		2			2	8
Pisaster brevispinus		2					6	8
Crangon alba	5			2				7
Ophiothrix spiculata				7				7
Pyromaia tuberculata					3		3	6
Acanthodoris rhodoceras	1	4						5
Kelletia kelletii		2	1			1	1	5
Crangon nigromaculata	1				2		1	4
Crossata californica		2		1	1			4
Flabellina iodinea		1	2					3
Pandalus danae					3			3
Dendronotus iris							2	2
Lytechinus pictus				2				2
Metacarcinus anthonyi					1		1	2
Pagurus spilocarpus		1		1				2
Sicyonia penicillata						1	1	2
Antiplanes catalinae				1				1
Cancridae		1						1
Lamellaria diegoensis	1							1
Loxorhynchus grandis						1		1
Luidia armata				1				1
Megastraea turbanica				1				1
Quarter Total	121	45	215	73	19	17	47	537
Annual Total	**328**	**305**	**372**	**360**	**104**	**122**	**333**	**1924**

Appendix F

Supporting Data

2010 SBOO Stations

Bioaccumulation of Contaminants in Fish Tissues

Appendix F.1

Lengths and weights of fishes used for each composite sample for the SBOO monitoring program during April and October 2010. Data are summarized as number of individuals (*n*), minimum, maximum, and mean values.

				Length (cm, size class)			Weight (g)		
Station	**Comp**	**Species**	***n***	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
April 2010									
RF3	1	Brown rockfish	3	24	29	26	343	391	371
RF3	2	Brown rockfish	3	14	32	23	83	965	459
RF3	3	Mixed rockfish	3	16	23	19	92	278	196
RF4	1	Ca. scorpionfish	3	20	28	25	653	801	716
RF4	2	Ca. scorpionfish	3	21	27	25	267	618	499
RF4	3	Ca. scorpionfish	3	24	29	26	367	733	565
SD15	1	(no sample)	—	—	—	—	—	—	—
SD15	2	(no sample)	—	—	—	—	—	—	—
SD15	3	(no sample)	—	—	—	—	—	—	—
SD16	1	English sole	4	17	26	21	71	233	143
SD16	2	(no sample)	—	—	—	—	—	—	—
SD16	3	(no sample)	—	—	—	—	—	—	—
SD17	1	English sole	9	13	25	18	28	181	95
SD17	2	Longfin sanddab	12	13	18	15	39	123	61
SD17	3	Hornyhead turbot	7	14	21	17	81	238	139
SD18	1	English sole	5	17	25	20	62	221	124
SD18	2	English sole	13	13	23	18	30	154	77
SD18	3	Hornyhead turbot	7	16	20	18	96	188	133
SD19	1	Longfin sanddab	15	13	18	14	32	100	54
SD19	2	English sole	9	13	20	17	28	155	80
SD19	3	Hornyhead turbot	5	13	18	16	55	142	108
SD20	1	Hornyhead turbot	5	12	21	16	52	247	109
SD20	2	Hornyhead turbot	3	20	21	20	226	297	250
SD20	3	English sole	10	14	25	18	40	217	84
SD21	1	Hornyhead turbot	4	17	21	19	99	228	170
SD21	2	Hornyhead turbot	3	16	23	20	87	345	211
SD21	3	English sole	5	15	24	20	49	188	108

Appendix F.1 *continued*

Station	Comp	Species	*n*	Length (cm, size class) Min	Length (cm, size class) Max	Length (cm, size class) Mean	Weight (g) Min	Weight (g) Max	Weight (g) Mean
October 2010									
RF3	1	Brown rockfish	3	21	36	29	279	1420	849
RF3	2	Brown rockfish	3	18	22	20	174	272	239
RF3	3	Brown rockfish	3	16	28	21	132	594	338
RF4	1	Ca. scorpionfish	3	21	30	26	336	841	586
RF4	2	Ca. scorpionfish	3	21	23	22	267	368	331
RF4	3	Ca. scorpionfish	3	19	26	22	209	511	346
SD15	1	Hornyhead turbot	5	17	19	17	135	197	152
SD15	2	English sole	3	19	27	23	134	373	246
SD15	3	Ca. scorpionfish	3	21	22	21	300	389	336
SD16	1	Longfin sanddab	7	14	19	15	53	160	75
SD16	2	English sole	4	17	23	20	92	237	154
SD16	3	Longfin sanddab	7	13	17	15	41	109	71
SD17	1	Longfin sanddab	3	16	18	17	82	132	112
SD17	2	Longfin sanddab	4	17	19	18	94	130	110
SD17	3	Hornyhead turbot	4	18	21	19	177	248	200
SD18	1	Longfin sanddab	5	14	17	16	77	114	98
SD18	2	Longfin sanddab	5	14	20	17	56	148	96
SD18	3	Longfin sanddab	6	14	19	16	52	148	81
SD19	1	Longfin sanddab	3	18	19	18	117	158	136
SD19	2	Longfin sanddab	4	14	19	17	68	156	112
SD19	3	Longfin sanddab	7	14	17	15	58	101	75
SD20	1	Longfin sanddab	7	13	16	14	46	101	66
SD20	2	Longfin sanddab	5	14	16	15	55	86	66
SD20	3	(no sample)	—	—	—	—	—	—	—
SD21	1	Longfin sanddab	6	14	17	15	50	95	65
SD21	2	Longfin sanddab	8	12	15	14	42	76	59
SD21	3	Hornyhead turbot	6	13	20	16	66	176	119

Appendix F.2

Constituents and method detection limits (MDL) for fish tissue samples analyzed for the SBOO monitoring program during April and October 2010.

	MDL			MDL	
Parameter	**Liver**	**Muscle**	**Parameter**	**Liver**	**Muscle**
		Metals (ppm)			
Aluminum (Al)	3	3	Lead (Pb)	0.2	0.2
Antimony (Sb)	0.2	0.2	Manganese (Mn)	0.1	0.1
Arsenic (As)	0.24	0.24	Mercury (Hg)	0.01	0.01
Barium (Ba)	0.03	0.03	Nickel (Ni)	0.2	0.2
Beryllium (Be)	0.006	0.006	Selenium (Se)	0.06	0.06
Cadmium (Cd)	0.06	0.06	Silver (Ag)	0.05	0.05
Chromium (Cr)	0.1	0.1	Thallium (Tl)	0.4	0.4
Copper (Cu)	0.1	0.1	Tin (Sn)	0.2	0.2
Iron (Fe)	2	2	Zinc (Zn)	0.15	0.15
		Chlorinated Pesticides (ppb)			
		Hexachlorocyclohexane (HCH)			
HCH, Alpha isomer	24.7	2.47	HCH, Delta isomer	4.53	0.45
HCH, Beta isomer	4.68	0.47	HCH, Gamma isomer	63.4	6.34
		Total Chlordane			
Alpha (cis) Chlordane	4.56	0.46	Heptachlor epoxide	3.89	0.39
Cis Nonachlor	4.7	0.47	Oxychlordane	7.77	0.78
Gamma (trans) Chlordane	2.59	0.26	Trans Nonachlor	2.58	0.26
Heptachlor	3.82	0.38			
		Total Dichlorodiphenyltrichloroethane (DDT)			
o,p-DDD	2.02	0.2	p,p-DDE	2.08	0.21
o,p-DDE	2.79	0.28	p,-p-DDMU	3.29	0.33
o,p-DDT	1.62	0.16	p,p-DDT	2.69	0.27
p,p-DDD	3.36	0.34			
		Miscellaneous Pesticides			
Aldrin	88.1	8.81	Hexachlorobenzene (HCB)	1.32	0.13
Alpha Endosulfan	118	11.8	Mirex	1.49	0.15
Dieldrin	17.1	1.71	Toxaphene	342	34.2
Endrin	14.2	1.42			

Appendix F.2 *continued*

Parameter	MDL Liver	MDL Muscle	Parameter	MDL Liver	MDL Muscle
Polychlorinated Biphenyls Congeners (PCBs) (ppb)					
PCB 18	2.86	0.29	PCB 126	1.52	0.15
PCB 28	2.47	0.28	PCB 128	1.23	0.12
PCB 37	2.77	0.25	PCB 138	1.73	0.17
PCB 44	3.65	0.36	PCB 149	2.34	0.23
PCB 49	5.02	0.50	PCB 151	1.86	0.19
PCB 52	5.32	0.53	PCB 153/168	2.54	0.25
PCB 66	2.81	0.28	PCB 156	0.64	0.06
PCB 70	2.49	0.25	PCB 157	2.88	0.29
PCB 74	3.10	0.31	PCB 158	2.72	0.27
PCB 77	2.01	0.20	PCB 167	1.63	0.16
PCB 81	3.56	0.36	PCB 169	2.76	0.28
PCB 87	3.01	0.30	PCB 170	1.23	0.12
PCB 99	3.05	0.30	PCB 177	1.91	0.19
PCB 101	4.34	0.43	PCB 180	2.58	0.26
PCB 105	2.29	0.23	PCB 183	1.55	0.15
PCB 110	2.50	0.25	PCB 187	2.50	0.25
PCB 114	3.15	0.31	PCB 189	1.78	0.18
PCB 118	2.06	0.21	PCB 194	1.14	0.11
PCB 119	2.39	0.24	PCB 201	2.88	0.29
PCB 123	2.64	0.26	PCB 206	1.28	0.13
Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)					
1-methylnaphthalene	17.4	23.3	Benzo[G,H,I]perylene	27.2	59.5
1-methylphenanthrene	27.9	26.4	Benzo[K]fluoranthene	32.0	37.3
2,3,5-trimethylnaphthalene	21.7	21.6	Biphenyl	38.0	19.9
2,6-dimethylnaphthalene	21.7	19.5	Chrysene	18.1	23.0
2-methylnaphthalene	35.8	13.2	Dibenzo(A,H)anthracene	37.6	40.3
3,4-benzo(B)fluoranthene	30.2	26.8	Fluoranthene	19.9	12.9
Acenaphthene	28.9	11.3	Fluorene	27.3	11.4
Acenaphthylene	24.7	9.1	Indeno(1,2,3-CD)pyrene	25.6	46.5
Anthracene	25.3	8.4	Naphthalene	34.2	17.4
Benzo[A]anthracene	47.3	15.9	Perylene	18.5	50.9
Benzo[A]pyrene	42.9	18.3	Phenanthrene	11.6	12.9
Benzo[e]pyrene	41.8	40.6	Pyrene	9.1	16.6

Appendix F.3

Summary of constituents that make up total DDT and total PCB in each composite sample collected as part of the SBOO monitoring program during April and October 2010.

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-2	RF3	1	Brown rockfish	Muscle	DDT	p,p-DDE	3.6	ppb
2010-2	RF3	1	Brown rockfish	Muscle	PCB	PCB 66	0.1	ppb
2010-2	RF3	1	Brown rockfish	Muscle	PCB	PCB 99	0.2	ppb
2010-2	RF3	1	Brown rockfish	Muscle	PCB	PCB 101	0.3	ppb
2010-2	RF3	1	Brown rockfish	Muscle	PCB	PCB 118	0.3	ppb
2010-2	RF3	1	Brown rockfish	Muscle	PCB	PCB 138	0.5	ppb
2010-2	RF3	1	Brown rockfish	Muscle	PCB	PCB 149	0.2	ppb
2010-2	RF3	1	Brown rockfish	Muscle	PCB	PCB 153/168	0.8	ppb
2010-2	RF3	1	Brown rockfish	Muscle	PCB	PCB 180	0.2	ppb
2010-2	RF3	1	Brown rockfish	Muscle	PCB	PCB 187	0.3	ppb
2010-2	RF3	1	Brown rockfish	Muscle	PCB	PCB 194	0.1	ppb
2010-2	RF3	2	Brown rockfish	Muscle	DDT	p,p-DDE	2.1	ppb
2010-2	RF3	2	Brown rockfish	Muscle	PCB	PCB 138	0.1	ppb
2010-2	RF3	2	Brown rockfish	Muscle	PCB	PCB 153/168	0.2	ppb
2010-2	RF3	3	Mixed Rockfish	Muscle	DDT	p,p-DDE	2	ppb
2010-2	RF3	3	Mixed Rockfish	Muscle	PCB	PCB 153/168	0.2	ppb
2010-2	RF4	1	California scorpionfish	Muscle	DDT	p,p-DDE	3.7	ppb
2010-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 66	0.1	ppb
2010-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 99	0.3	ppb
2010-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 101	0.3	ppb
2010-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 105	0.1	ppb
2010-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 110	0.2	ppb
2010-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 118	0.6	ppb
2010-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 138	0.8	ppb
2010-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 149	0.2	ppb
2010-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 151	0.2	ppb
2010-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 153/168	2.5	ppb
2010-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 170	0.4	ppb
2010-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 177	0.3	ppb
2010-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 180	2.5	ppb
2010-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 183	0.5	ppb
2010-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 187	1.7	ppb
2010-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 194	0.7	ppb
2010-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 201	0.9	ppb
2010-2	RF4	2	California scorpionfish	Muscle	DDT	p,p-DDE	4.3	ppb
2010-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 66	0.1	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 74	0.1	ppb
2010-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 99	0.4	ppb
2010-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 101	0.4	ppb
2010-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 105	0.1	ppb
2010-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 110	0.2	ppb
2010-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 118	0.5	ppb
2010-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 138	0.7	ppb
2010-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 149	0.3	ppb
2010-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 153/168	1.4	ppb
2010-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 170	0.2	ppb
2010-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 180	0.4	ppb
2010-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 183	0.1	ppb
2010-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 187	0.4	ppb
2010-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 194	0.1	ppb
2010-2	RF4	3	California scorpionfish	Muscle	DDT	p,p-DDD	0.4	ppb
2010-2	RF4	3	California scorpionfish	Muscle	DDT	p,p-DDE	17	ppb
2010-2	RF4	3	California scorpionfish	Muscle	DDT	p,-p-DDMU	0.4	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 52	0.2	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 66	0.1	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 70	0.1	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 74	0.1	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 99	0.85	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 101	0.55	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 105	0.25	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 110	0.3	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 118	1.1	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 128	0.15	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 138	1.1	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 149	0.2	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 153/168	1.95	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 170	0.25	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 180	0.6	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 183	0.1	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 187	0.5	ppb
2010-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 194	0.2	ppb
2010-2	SD16	1	English sole	Liver	DDT	p,p-DDE	49	ppb
2010-2	SD16	1	English sole	Liver	PCB	PCB 99	2.8	ppb
2010-2	SD16	1	English sole	Liver	PCB	PCB 118	3.1	ppb
2010-2	SD16	1	English sole	Liver	PCB	PCB 138	3.8	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-2	SD16	1	English sole	Liver	PCB	PCB 149	1.9	ppb
2010-2	SD16	1	English sole	Liver	PCB	PCB 153/168	7.4	ppb
2010-2	SD16	1	English sole	Liver	PCB	PCB 180	2.5	ppb
2010-2	SD16	1	English sole	Liver	PCB	PCB 187	3	ppb
2010-2	SD17	1	English sole	Liver	DDT	o,p-DDE	11	ppb
2010-2	SD17	1	English sole	Liver	DDT	p,p-DDD	3.9	ppb
2010-2	SD17	1	English sole	Liver	DDT	p,p-DDE	180	ppb
2010-2	SD17	1	English sole	Liver	DDT	p,-p-DDMU	14	ppb
2010-2	SD17	1	English sole	Liver	PCB	PCB 66	1.6	ppb
2010-2	SD17	1	English sole	Liver	PCB	PCB 70	0.9	ppb
2010-2	SD17	1	English sole	Liver	PCB	PCB 74	0.8	ppb
2010-2	SD17	1	English sole	Liver	PCB	PCB 99	4.5	ppb
2010-2	SD17	1	English sole	Liver	PCB	PCB 101	5.2	ppb
2010-2	SD17	1	English sole	Liver	PCB	PCB 110	3.2	ppb
2010-2	SD17	1	English sole	Liver	PCB	PCB 118	4.7	ppb
2010-2	SD17	1	English sole	Liver	PCB	PCB 138	5.7	ppb
2010-2	SD17	1	English sole	Liver	PCB	PCB 149	3.4	ppb
2010-2	SD17	1	English sole	Liver	PCB	PCB 153/168	10	ppb
2010-2	SD17	1	English sole	Liver	PCB	PCB 180	3.2	ppb
2010-2	SD17	1	English sole	Liver	PCB	PCB 187	5.2	ppb
2010-2	SD17	2	Longfin sanddab	Liver	DDT	o,p-DDE	4.5	ppb
2010-2	SD17	2	Longfin sanddab	Liver	DDT	p,p-DDE	270	ppb
2010-2	SD17	2	Longfin sanddab	Liver	DDT	p,-p-DDMU	7.2	ppb
2010-2	SD17	2	Longfin sanddab	Liver	DDT	p,p-DDT	5.6	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 49	1.4	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 52	1.9	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 66	1.5	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 70	0.9	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 74	1.1	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 99	13	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 101	7.4	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 105	3.2	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 110	3.8	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 118	14	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 128	3.5	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 138	23	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 149	5.6	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 151	3.3	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 153/168	44	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 158	1.6	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 170	6.1	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 177	3.8	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 180	15	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 183	5.1	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 187	17	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 194	5.5	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 201	5.8	ppb
2010-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 206	3.1	ppb
2010-2	SD17	3	Hornyhead turbot	Liver	DDT	p,p-DDE	100	ppb
2010-2	SD17	3	Hornyhead turbot	Liver	DDT	p,-p-DDMU	4.1	ppb
2010-2	SD17	3	Hornyhead turbot	Liver	PCB	PCB 99	3	ppb
2010-2	SD17	3	Hornyhead turbot	Liver	PCB	PCB 101	2.3	ppb
2010-2	SD17	3	Hornyhead turbot	Liver	PCB	PCB 118	3.2	ppb
2010-2	SD17	3	Hornyhead turbot	Liver	PCB	PCB 138	4.7	ppb
2010-2	SD17	3	Hornyhead turbot	Liver	PCB	PCB 149	1.9	ppb
2010-2	SD17	3	Hornyhead turbot	Liver	PCB	PCB 153/168	9.4	ppb
2010-2	SD17	3	Hornyhead turbot	Liver	PCB	PCB 180	5	ppb
2010-2	SD17	3	Hornyhead turbot	Liver	PCB	PCB 183	1.4	ppb
2010-2	SD17	3	Hornyhead turbot	Liver	PCB	PCB 187	3.8	ppb
2010-2	SD17	3	Hornyhead turbot	Liver	PCB	PCB 194	1.5	ppb
2010-2	SD18	1	English sole	Liver	DDT	o,p-DDE	1.5	ppb
2010-2	SD18	1	English sole	Liver	DDT	p,p-DDE	49	ppb
2010-2	SD18	1	English sole	Liver	PCB	PCB 99	2.1	ppb
2010-2	SD18	1	English sole	Liver	PCB	PCB 101	2.7	ppb
2010-2	SD18	1	English sole	Liver	PCB	PCB 105	0.8	ppb
2010-2	SD18	1	English sole	Liver	PCB	PCB 118	2.7	ppb
2010-2	SD18	1	English sole	Liver	PCB	PCB 138	4.1	ppb
2010-2	SD18	1	English sole	Liver	PCB	PCB 149	2.6	ppb
2010-2	SD18	1	English sole	Liver	PCB	PCB 153/168	7.4	ppb
2010-2	SD18	1	English sole	Liver	PCB	PCB 180	2.9	ppb
2010-2	SD18	1	English sole	Liver	PCB	PCB 187	3.8	ppb
2010-2	SD18	1	English sole	Liver	PCB	PCB 194	1.6	ppb
2010-2	SD18	2	English sole	Liver	DDT	o,p-DDE	2.3	ppb
2010-2	SD18	2	English sole	Liver	DDT	p,p-DDD	2.1	ppb
2010-2	SD18	2	English sole	Liver	DDT	p,p-DDE	96	ppb
2010-2	SD18	2	English sole	Liver	DDT	p,-p-DDMU	2.4	ppb
2010-2	SD18	2	English sole	Liver	DDT	p,p-DDT	2.2	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-2	SD18	2	English sole	Liver	PCB	PCB 49	1.3	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 52	1.4	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 66	1.6	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 70	1	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 74	0.9	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 99	6.6	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 101	8.1	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 105	1.8	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 110	3.8	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 118	6.6	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 128	2.5	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 138	12	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 149	6.9	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 151	2.5	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 153/168	20	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 170	2.6	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 177	2.1	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 180	7.1	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 183	2.6	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 187	7.6	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 194	2.7	ppb
2010-2	SD18	2	English sole	Liver	PCB	PCB 201	2.5	ppb
2010-2	SD18	3	Hornyhead turbot	Liver	DDT	o,p-DDE	1.45	ppb
2010-2	SD18	3	Hornyhead turbot	Liver	DDT	p,p-DDD	2.65	ppb
2010-2	SD18	3	Hornyhead turbot	Liver	DDT	p,p-DDE	94	ppb
2010-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 99	3.05	ppb
2010-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 101	2.15	ppb
2010-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 118	2.95	ppb
2010-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 138	4.3	ppb
2010-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 149	1.6	ppb
2010-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 153/168	9.45	ppb
2010-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 170	2	ppb
2010-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 180	5.3	ppb
2010-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 183	1.7	ppb
2010-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 187	4.15	ppb
2010-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 194	2.15	ppb
2010-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 201	1.8	ppb
2010-2	SD19	1	Longfin sanddab	Liver	DDT	o,p-DDE	1.8	ppb
2010-2	SD19	1	Longfin sanddab	Liver	DDT	p,p-DDD	2.9	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-2	SD19	1	Longfin sanddab	Liver	DDT	p,p-DDE	270	ppb
2010-2	SD19	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	3.6	ppb
2010-2	SD19	1	Longfin sanddab	Liver	DDT	p,p-DDT	4.4	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 49	1	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 52	2.1	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 66	1.7	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 74	1	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 99	13	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 101	7.5	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 105	3.2	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 110	4.3	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 118	18	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 128	5.3	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 138	31	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 149	5.1	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 151	5	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 153/168	59	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 158	2.5	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 167	1.7	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 170	9.3	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 177	4	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 180	23	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 183	7.1	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 187	22	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 194	8.2	ppb
2010-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 201	7.2	ppb
2010-2	SD19	2	English sole	Liver	DDT	o,p-DDE	11	ppb
2010-2	SD19	2	English sole	Liver	DDT	p,p-DDD	3.5	ppb
2010-2	SD19	2	English sole	Liver	DDT	p,p-DDE	270	ppb
2010-2	SD19	2	English sole	Liver	DDT	p,-p-DDMU	15	ppb
2010-2	SD19	2	English sole	Liver	PCB	PCB 49	1.6	ppb
2010-2	SD19	2	English sole	Liver	PCB	PCB 52	1.2	ppb
2010-2	SD19	2	English sole	Liver	PCB	PCB 66	1.5	ppb
2010-2	SD19	2	English sole	Liver	PCB	PCB 70	1	ppb
2010-2	SD19	2	English sole	Liver	PCB	PCB 74	0.9	ppb
2010-2	SD19	2	English sole	Liver	PCB	PCB 99	4.1	ppb
2010-2	SD19	2	English sole	Liver	PCB	PCB 101	5.4	ppb
2010-2	SD19	2	English sole	Liver	PCB	PCB 105	1.6	ppb
2010-2	SD19	2	English sole	Liver	PCB	PCB 110	2.5	ppb
2010-2	SD19	2	English sole	Liver	PCB	PCB 118	5.4	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-2	SD19	2	English sole	Liver	PCB	PCB 138	7	ppb
2010-2	SD19	2	English sole	Liver	PCB	PCB 149	5.1	ppb
2010-2	SD19	2	English sole	Liver	PCB	PCB 153/168	11	ppb
2010-2	SD19	2	English sole	Liver	PCB	PCB 170	1.5	ppb
2010-2	SD19	2	English sole	Liver	PCB	PCB 180	3.2	ppb
2010-2	SD19	2	English sole	Liver	PCB	PCB 187	5.2	ppb
2010-2	SD19	3	Hornyhead turbot	Liver	DDT	p,p-DDE	82	ppb
2010-2	SD19	3	Hornyhead turbot	Liver	DDT	p,-p-DDMU	1.5	ppb
2010-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 74	0.5	ppb
2010-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 99	2	ppb
2010-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 101	1.9	ppb
2010-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 118	2.4	ppb
2010-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 138	3.8	ppb
2010-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 149	2.3	ppb
2010-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 153/168	8.1	ppb
2010-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 180	3.2	ppb
2010-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 187	2.9	ppb
2010-2	SD20	1	Hornyhead turbot	Liver	DDT	p,p-DDE	43	ppb
2010-2	SD20	1	Hornyhead turbot	Liver	DDT	p,-p-DDMU	1.5	ppb
2010-2	SD20	1	Hornyhead turbot	Liver	PCB	PCB 138	2.3	ppb
2010-2	SD20	1	Hornyhead turbot	Liver	PCB	PCB 153/168	5.1	ppb
2010-2	SD20	1	Hornyhead turbot	Liver	PCB	PCB 180	1.7	ppb
2010-2	SD20	1	Hornyhead turbot	Liver	PCB	PCB 187	2.2	ppb
2010-2	SD20	1	Hornyhead turbot	Liver	PCB	PCB 194	1.1	ppb
2010-2	SD20	2	Hornyhead turbot	Liver	DDT	p,p-DDE	47	ppb
2010-2	SD20	2	Hornyhead turbot	Liver	DDT	p,-p-DDMU	3.9	ppb
2010-2	SD20	2	Hornyhead turbot	Liver	PCB	PCB 52	0.7	ppb
2010-2	SD20	2	Hornyhead turbot	Liver	PCB	PCB 99	2.1	ppb
2010-2	SD20	2	Hornyhead turbot	Liver	PCB	PCB 118	1.8	ppb
2010-2	SD20	2	Hornyhead turbot	Liver	PCB	PCB 138	3.9	ppb
2010-2	SD20	2	Hornyhead turbot	Liver	PCB	PCB 153/168	5.1	ppb
2010-2	SD20	2	Hornyhead turbot	Liver	PCB	PCB 180	1.9	ppb
2010-2	SD20	2	Hornyhead turbot	Liver	PCB	PCB 187	2	ppb
2010-2	SD20	2	Hornyhead turbot	Liver	PCB	PCB 194	1	ppb
2010-2	SD20	3	English sole	Liver	DDT	o,p-DDE	3.2	ppb
2010-2	SD20	3	English sole	Liver	DDT	p,p-DDD	2.4	ppb
2010-2	SD20	3	English sole	Liver	DDT	p,p-DDE	98	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-2	SD20	3	English sole	Liver	DDT	p,-p-DDMU	3.5	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 49	1.7	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 52	1.5	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 66	1.3	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 70	1.3	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 74	0.9	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 99	6.2	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 101	8.9	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 105	1.6	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 110	5.5	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 118	7.6	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 128	2.4	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 138	12	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 149	8.7	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 151	3.8	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 153/168	23	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 170	3.4	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 177	2.7	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 180	8.3	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 183	2.9	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 187	11	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 194	3.9	ppb
2010-2	SD20	3	English sole	Liver	PCB	PCB 201	5.2	ppb
2010-2	SD21	1	Hornyhead turbot	Liver	DDT	p,p-DDE	48	ppb
2010-2	SD21	1	Hornyhead turbot	Liver	DDT	p,-p-DDMU	2	ppb
2010-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 49	0.9	ppb
2010-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 52	1	ppb
2010-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 66	0.6	ppb
2010-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 99	3.4	ppb
2010-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 101	2.2	ppb
2010-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 118	3.7	ppb
2010-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 138	7.6	ppb
2010-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 149	1.9	ppb
2010-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 153/168	9.1	ppb
2010-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 180	2.9	ppb
2010-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 183	1.1	ppb
2010-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 187	3.7	ppb
2010-2	SD21	2	Hornyhead turbot	Liver	DDT	p,p-DDE	48	ppb
2010-2	SD21	2	Hornyhead turbot	Liver	DDT	p,-p-DDMU	1.85	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-2	SD21	2	Hornyhead turbot	Liver	PCB	PCB 49	0.95	ppb
2010-2	SD21	2	Hornyhead turbot	Liver	PCB	PCB 66	0.5	ppb
2010-2	SD21	2	Hornyhead turbot	Liver	PCB	PCB 74	0.35	ppb
2010-2	SD21	2	Hornyhead turbot	Liver	PCB	PCB 99	3.25	ppb
2010-2	SD21	2	Hornyhead turbot	Liver	PCB	PCB 101	2.65	ppb
2010-2	SD21	2	Hornyhead turbot	Liver	PCB	PCB 118	3.45	ppb
2010-2	SD21	2	Hornyhead turbot	Liver	PCB	PCB 138	5.35	ppb
2010-2	SD21	2	Hornyhead turbot	Liver	PCB	PCB 149	2.65	ppb
2010-2	SD21	2	Hornyhead turbot	Liver	PCB	PCB 153/168	9.85	ppb
2010-2	SD21	2	Hornyhead turbot	Liver	PCB	PCB 170	1.25	ppb
2010-2	SD21	2	Hornyhead turbot	Liver	PCB	PCB 180	3.15	ppb
2010-2	SD21	2	Hornyhead turbot	Liver	PCB	PCB 183	1.2	ppb
2010-2	SD21	2	Hornyhead turbot	Liver	PCB	PCB 187	3.8	ppb
2010-2	SD21	3	English sole	Liver	DDT	o,p-DDE	1.5	ppb
2010-2	SD21	3	English sole	Liver	DDT	p,p-DDE	45	ppb
2010-2	SD21	3	English sole	Liver	DDT	p,-p-DDMU	1.8	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 49	1	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 52	1	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 66	0.8	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 70	0.6	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 74	0.5	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 99	3.7	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 101	4.6	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 110	1.7	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 118	3.6	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 138	6.1	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 149	4.1	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 153/168	13	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 170	2.2	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 177	1.9	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 180	4.7	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 183	1.5	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 187	6.1	ppb
2010-2	SD21	3	English sole	Liver	PCB	PCB 201	1.9	ppb
2010-4	RF3	1	Brown rockfish	Muscle	DDT	p,p-DDE	1.3	ppb
2010-4	RF3	1	Brown rockfish	Muscle	PCB	PCB 153/168	0.5	ppb
2010-4	RF3	2	Brown rockfish	Muscle	DDT	p,p-DDE	1	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-4	RF3	3	Brown rockfish	Muscle	DDT	p,p-DDE	2	ppb
2010-4	RF3	3	Brown rockfish	Muscle	PCB	PCB 153/168	0.8	ppb
2010-4	RF4	1	California scorpionfish	Muscle	DDT	p,p-DDE	6	ppb
2010-4	RF4	1	California scorpionfish	Muscle	DDT	p,-p-DDMU	0.5	ppb
2010-4	RF4	1	California scorpionfish	Muscle	PCB	PCB 153/168	0.6	ppb
2010-4	RF4	2	California scorpionfish	Muscle	DDT	p,p-DDE	1.9	ppb
2010-4	RF4	2	California scorpionfish	Muscle	PCB	PCB 153/168	0.7	ppb
2010-4	RF4	3	California scorpionfish	Muscle	DDT	p,p-DDE	1.5	ppb
2010-4	RF4	3	California scorpionfish	Muscle	PCB	PCB 153/168	0.4	ppb
2010-4	SD15	1	Hornyhead turbot	Liver	DDT	p,p-DDE	9.4	ppb
2010-4	SD15	1	Hornyhead turbot	Liver	PCB	PCB 138	2.1	ppb
2010-4	SD15	1	Hornyhead turbot	Liver	PCB	PCB 153/168	2.3	ppb
2010-4	SD15	2	English sole	Liver	DDT	p,p-DDE	23	ppb
2010-4	SD15	2	English sole	Liver	PCB	PCB 70	0.7	ppb
2010-4	SD15	2	English sole	Liver	PCB	PCB 118	3.5	ppb
2010-4	SD15	2	English sole	Liver	PCB	PCB 138	4.3	ppb
2010-4	SD15	2	English sole	Liver	PCB	PCB 149	2.7	ppb
2010-4	SD15	2	English sole	Liver	PCB	PCB 153/168	8.8	ppb
2010-4	SD15	2	English sole	Liver	PCB	PCB 187	4.8	ppb
2010-4	SD15	3	California scorpionfish	Liver	DDT	p,p-DDE	74	ppb
2010-4	SD15	3	California scorpionfish	Liver	DDT	p,-p-DDMU	3.7	ppb
2010-4	SD15	3	California scorpionfish	Liver	PCB	PCB 66	1.5	ppb
2010-4	SD15	3	California scorpionfish	Liver	PCB	PCB 74	1.6	ppb
2010-4	SD15	3	California scorpionfish	Liver	PCB	PCB 99	7.6	ppb
2010-4	SD15	3	California scorpionfish	Liver	PCB	PCB 101	10	ppb
2010-4	SD15	3	California scorpionfish	Liver	PCB	PCB 118	10	ppb
2010-4	SD15	3	California scorpionfish	Liver	PCB	PCB 138	12	ppb
2010-4	SD15	3	California scorpionfish	Liver	PCB	PCB 149	3.9	ppb
2010-4	SD15	3	California scorpionfish	Liver	PCB	PCB 151	2.9	ppb
2010-4	SD15	3	California scorpionfish	Liver	PCB	PCB 153/168	27	ppb
2010-4	SD15	3	California scorpionfish	Liver	PCB	PCB 180	8.7	ppb
2010-4	SD15	3	California scorpionfish	Liver	PCB	PCB 187	8	ppb
2010-4	SD15	3	California scorpionfish	Liver	PCB	PCB 194	4.8	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-4	SD16	1	Longfin sanddab	Liver	DDT	o,p-DDE	6.6	ppb
2010-4	SD16	1	Longfin sanddab	Liver	DDT	p,p-DDD	4.3	ppb
2010-4	SD16	1	Longfin sanddab	Liver	DDT	p,p-DDE	130	ppb
2010-4	SD16	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	7.6	ppb
2010-4	SD16	1	Longfin sanddab	Liver	DDT	p,p-DDT	4.5	ppb
2010-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 66	1.1	ppb
2010-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 70	1.2	ppb
2010-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 74	1.8	ppb
2010-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 99	7.6	ppb
2010-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 101	4.5	ppb
2010-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 105	3	ppb
2010-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 118	12	ppb
2010-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 138	23	ppb
2010-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 149	4.6	ppb
2010-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 151	3.5	ppb
2010-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 153/168	49	ppb
2010-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 180	19	ppb
2010-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 187	17	ppb
2010-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 194	5.7	ppb
2010-4	SD16	2	English sole	Liver	DDT	p,p-DDE	11	ppb
2010-4	SD16	2	English sole	Liver	PCB	PCB 138	5.4	ppb
2010-4	SD16	2	English sole	Liver	PCB	PCB 149	2.9	ppb
2010-4	SD16	2	English sole	Liver	PCB	PCB 153/168	9.6	ppb
2010-4	SD16	2	English sole	Liver	PCB	PCB 180	5.9	ppb
2010-4	SD16	2	English sole	Liver	PCB	PCB 183	3.1	ppb
2010-4	SD16	2	English sole	Liver	PCB	PCB 187	5	ppb
2010-4	SD16	2	English sole	Liver	PCB	PCB 206	5	ppb
2010-4	SD16	3	Longfin sanddab	Liver	DDT	o,p-DDE	4.9	ppb
2010-4	SD16	3	Longfin sanddab	Liver	DDT	p,p-DDD	4	ppb
2010-4	SD16	3	Longfin sanddab	Liver	DDT	p,p-DDE	120	ppb
2010-4	SD16	3	Longfin sanddab	Liver	DDT	p,-p-DDMU	7.3	ppb
2010-4	SD16	3	Longfin sanddab	Liver	DDT	p,p-DDT	4.4	ppb
2010-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 66	1.7	ppb
2010-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 74	1.3	ppb
2010-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 99	12	ppb
2010-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 101	5.2	ppb
2010-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 105	3.7	ppb
2010-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 118	12	ppb
2010-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 138	28	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 149	3.7	ppb
2010-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 151	4.3	ppb
2010-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 153/168	64	ppb
2010-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 167	2.6	ppb
2010-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 170	9.5	ppb
2010-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 180	23	ppb
2010-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 183	7	ppb
2010-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 187	24	ppb
2010-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 194	9.9	ppb
2010-4	SD17	1	Longfin sanddab	Liver	DDT	o,p-DDE	4.7	ppb
2010-4	SD17	1	Longfin sanddab	Liver	DDT	p,p-DDD	5.5	ppb
2010-4	SD17	1	Longfin sanddab	Liver	DDT	p,p-DDE	100	ppb
2010-4	SD17	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	8.4	ppb
2010-4	SD17	1	Longfin sanddab	Liver	DDT	p,p-DDT	5.7	ppb
2010-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 66	1.7	ppb
2010-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 70	1.5	ppb
2010-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 74	1.1	ppb
2010-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 99	12	ppb
2010-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 101	7.9	ppb
2010-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 118	12	ppb
2010-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 138	15	ppb
2010-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 149	6.2	ppb
2010-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 151	4.3	ppb
2010-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 153/168	33	ppb
2010-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 180	11	ppb
2010-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 187	12	ppb
2010-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 194	6	ppb
2010-4	SD17	2	Longfin sanddab	Liver	DDT	o,p-DDE	3.2	ppb
2010-4	SD17	2	Longfin sanddab	Liver	DDT	p,p-DDE	62	ppb
2010-4	SD17	2	Longfin sanddab	Liver	DDT	p,-p-DDMU	4.8	ppb
2010-4	SD17	2	Longfin sanddab	Liver	PCB	PCB 66	1.3	ppb
2010-4	SD17	2	Longfin sanddab	Liver	PCB	PCB 70	0.8	ppb
2010-4	SD17	2	Longfin sanddab	Liver	PCB	PCB 74	0.9	ppb
2010-4	SD17	2	Longfin sanddab	Liver	PCB	PCB 99	6.4	ppb
2010-4	SD17	2	Longfin sanddab	Liver	PCB	PCB 101	5.2	ppb
2010-4	SD17	2	Longfin sanddab	Liver	PCB	PCB 118	8.6	ppb
2010-4	SD17	2	Longfin sanddab	Liver	PCB	PCB 138	12	ppb
2010-4	SD17	2	Longfin sanddab	Liver	PCB	PCB 149	2.4	ppb
2010-4	SD17	2	Longfin sanddab	Liver	PCB	PCB 153/168	26	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-4	SD17	2	Longfin sanddab	Liver	PCB	PCB 180	9.4	ppb
2010-4	SD17	2	Longfin sanddab	Liver	PCB	PCB 187	9	ppb
2010-4	SD17	3	Hornyhead turbot	Liver	DDT	p,p-DDE	28	ppb
2010-4	SD17	3	Hornyhead turbot	Liver	DDT	p,-p-DDMU	4	ppb
2010-4	SD17	3	Hornyhead turbot	Liver	PCB	PCB 138	3.3	ppb
2010-4	SD17	3	Hornyhead turbot	Liver	PCB	PCB 153/168	7.8	ppb
2010-4	SD18	1	Longfin sanddab	Liver	DDT	o,p-DDE	4.55	ppb
2010-4	SD18	1	Longfin sanddab	Liver	DDT	p,p-DDD	6.4	ppb
2010-4	SD18	1	Longfin sanddab	Liver	DDT	p,p-DDE	150	ppb
2010-4	SD18	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	11	ppb
2010-4	SD18	1	Longfin sanddab	Liver	DDT	p,p-DDT	7.05	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 49	3.25	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 52	3.4	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 66	4.55	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 70	4	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 74	4.45	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 99	15.5	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 101	11.8	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 105	7	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 110	6.85	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 118	19	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 119	5.5	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 128	10.1	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 138	27.5	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 149	11.4	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 151	9	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 153/168	56	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 156	6.85	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 157	7.85	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 158	5.8	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 167	6.5	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 170	11	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 177	9.3	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 180	22.5	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 183	10	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 187	21.5	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 194	14.4	ppb
2010-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 206	9.65	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-4	SD18	2	Longfin sanddab	Liver	DDT	o,p-DDE	4.9	ppb
2010-4	SD18	2	Longfin sanddab	Liver	DDT	p,p-DDD	6.5	ppb
2010-4	SD18	2	Longfin sanddab	Liver	DDT	p,p-DDE	120	ppb
2010-4	SD18	2	Longfin sanddab	Liver	DDT	p,-p-DDMU	9.2	ppb
2010-4	SD18	2	Longfin sanddab	Liver	DDT	p,p-DDT	5.5	ppb
2010-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 101	6.9	ppb
2010-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 66	1.8	ppb
2010-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 70	1.2	ppb
2010-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 74	1.6	ppb
2010-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 99	12	ppb
2010-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 110	4.5	ppb
2010-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 118	15	ppb
2010-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 128	4.8	ppb
2010-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 138	23	ppb
2010-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 149	6.2	ppb
2010-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 151	4.7	ppb
2010-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 153/168	50	ppb
2010-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 180	21	ppb
2010-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 183	7.5	ppb
2010-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 187	20	ppb
2010-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 194	12	ppb
2010-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 206	7.7	ppb
2010-4	SD18	3	Longfin sanddab	Liver	DDT	o,p-DDE	7.2	ppb
2010-4	SD18	3	Longfin sanddab	Liver	DDT	p,p-DDD	11	ppb
2010-4	SD18	3	Longfin sanddab	Liver	DDT	p,p-DDE	150	ppb
2010-4	SD18	3	Longfin sanddab	Liver	DDT	p,-p-DDMU	11	ppb
2010-4	SD18	3	Longfin sanddab	Liver	DDT	p,p-DDT	6.9	ppb
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 66	2.5	ppb
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 70	1.6	ppb
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 74	1.3	ppb
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 99	13	ppb
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 101	9.8	ppb
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 105	5.3	ppb
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 110	5.6	ppb
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 118	17	ppb
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 128	5.9	ppb
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 138	29	ppb
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 149	9.9	ppb
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 151	7.1	ppb
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 153/168	58	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 170	9.8	ppb
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 180	20	ppb
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 183	8	ppb
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 187	21	ppb
2010-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 194	9.2	ppb
2010-4	SD19	1	Longfin sanddab	Liver	DDT	o,p-DDE	7	ppb
2010-4	SD19	1	Longfin sanddab	Liver	DDT	p,p-DDD	11	ppb
2010-4	SD19	1	Longfin sanddab	Liver	DDT	p,p-DDE	120	ppb
2010-4	SD19	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	14	ppb
2010-4	SD19	1	Longfin sanddab	Liver	DDT	p,p-DDT	15	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 52	3.7	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 66	3.1	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 70	2.3	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 74	1.9	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 99	13	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 101	11	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 105	10	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 110	6.3	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 118	21	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 126	14	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 128	16	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 138	33	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 149	14	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 151	8.8	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 153/168	62	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 156	16	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 157	15	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 158	11	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 167	13	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 170	22	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 180	29	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 183	15	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 187	26	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 194	21	ppb
2010-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 206	18	ppb
2010-4	SD19	2	Longfin sanddab	Liver	DDT	o,p-DDE	8.2	ppb
2010-4	SD19	2	Longfin sanddab	Liver	DDT	p,p-DDD	9.3	ppb
2010-4	SD19	2	Longfin sanddab	Liver	DDT	p,p-DDE	170	ppb
2010-4	SD19	2	Longfin sanddab	Liver	DDT	p,-p-DDMU	16	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-4	SD19	2	Longfin sanddab	Liver	DDT	p,p-DDT	6	ppb
2010-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 66	2	ppb
2010-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 70	1.8	ppb
2010-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 74	1.4	ppb
2010-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 99	15	ppb
2010-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 101	8.1	ppb
2010-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 105	3.5	ppb
2010-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 110	5	ppb
2010-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 118	16	ppb
2010-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 128	5.4	ppb
2010-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 138	26	ppb
2010-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 149	9.4	ppb
2010-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 151	6	ppb
2010-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 153/168	56	ppb
2010-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 180	17	ppb
2010-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 183	5.9	ppb
2010-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 187	21	ppb
2010-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 194	7.5	ppb
2010-4	SD19	3	Longfin sanddab	Liver	DDT	o,p-DDE	4.6	ppb
2010-4	SD19	3	Longfin sanddab	Liver	DDT	p,p-DDD	6	ppb
2010-4	SD19	3	Longfin sanddab	Liver	DDT	p,p-DDE	110	ppb
2010-4	SD19	3	Longfin sanddab	Liver	DDT	p,-p-DDMU	8.9	ppb
2010-4	SD19	3	Longfin sanddab	Liver	DDT	p,p-DDT	2.7	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 66	1.7	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 70	0.7	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 74	1.3	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 99	7.6	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 101	4.6	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 110	2.9	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 118	11	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 128	4.4	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 138	21	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 149	5.2	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 151	5.3	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 153/168	39	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 180	13	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 183	4.7	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 187	19	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 66	1.7	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 70	0.7	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 74	1.3	ppb
2010-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 99	7.6	ppb
2010-4	SD20	1	Longfin sanddab	Liver	DDT	o,p-DDE	8.2	ppb
2010-4	SD20	1	Longfin sanddab	Liver	DDT	p,p-DDD	8.4	ppb
2010-4	SD20	1	Longfin sanddab	Liver	DDT	p,p-DDE	190	ppb
2010-4	SD20	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	14	ppb
2010-4	SD20	1	Longfin sanddab	Liver	DDT	p,p-DDT	7.7	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 49	2	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 52	3.2	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 66	2.4	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 70	1	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 74	2.1	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 99	24	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 101	9.5	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 118	31	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 128	9.8	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 138	53	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 149	8.3	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 151	7.1	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 153/168	99	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 170	14	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 177	7	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 180	32	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 183	10	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 187	37	ppb
2010-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 194	11	ppb
2010-4	SD20	2	Longfin sanddab	Liver	DDT	o,p-DDE	5.4	ppb
2010-4	SD20	2	Longfin sanddab	Liver	DDT	p,p-DDD	17	ppb
2010-4	SD20	2	Longfin sanddab	Liver	DDT	p,p-DDE	120	ppb
2010-4	SD20	2	Longfin sanddab	Liver	DDT	p,-p-DDMU	9	ppb
2010-4	SD20	2	Longfin sanddab	Liver	DDT	p,p-DDT	8.5	ppb
2010-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 66	1.5	ppb
2010-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 99	9.2	ppb
2010-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 101	5.4	ppb
2010-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 118	11	ppb
2010-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 128	3.8	ppb
2010-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 138	17	ppb
2010-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 149	6.2	ppb
2010-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 153/168	36	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 180	11	ppb
2010-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 187	12	ppb
2010-4	SD21	1	Longfin sanddab	Liver	DDT	o,p-DDE	5.2	ppb
2010-4	SD21	1	Longfin sanddab	Liver	DDT	p,p-DDD	7.6	ppb
2010-4	SD21	1	Longfin sanddab	Liver	DDT	p,p-DDE	89	ppb
2010-4	SD21	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	11	ppb
2010-4	SD21	1	Longfin sanddab	Liver	DDT	p,p-DDT	5.5	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 49	3.7	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 52	5.2	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 66	3.3	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 70	2	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 74	2.2	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 99	17	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 101	11	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 105	3.3	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 110	6.2	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 118	20	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 128	6.9	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 138	33	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 149	10	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 151	5	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 153/168	59	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 167	2.3	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 170	8.5	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 180	18	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 183	5	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 187	23	ppb
2010-4	SD21	1	Longfin sanddab	Liver	PCB	PCB 194	8.4	ppb
2010-4	SD21	2	Longfin sanddab	Liver	DDT	o,p-DDE	5.1	ppb
2010-4	SD21	2	Longfin sanddab	Liver	DDT	p,p-DDD	8.4	ppb
2010-4	SD21	2	Longfin sanddab	Liver	DDT	p,p-DDE	140	ppb
2010-4	SD21	2	Longfin sanddab	Liver	DDT	p,-p-DDMU	9.8	ppb
2010-4	SD21	2	Longfin sanddab	Liver	DDT	p,p-DDT	5.6	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 49	3.5	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 52	4.1	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 66	3.6	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 70	2.3	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 74	2.4	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 99	24	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 101	12	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 105	6.9	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 110	6.3	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 118	27	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 128	11	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 138	51	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 149	12	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 151	7.5	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 153/168	99	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 156	10	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 157	8.4	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 167	6.9	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 170	19	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 177	11	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 180	36	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 183	14	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 187	40	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 194	19	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 201	15	ppb
2010-4	SD21	2	Longfin sanddab	Liver	PCB	PCB 206	14	ppb
2010-4	SD21	3	Hornyhead turbot	Liver	DDT	p,p-DDE	18	ppb
2010-4	SD21	3	Hornyhead turbot	Liver	PCB	PCB 138	6.55	ppb
2010-4	SD21	3	Hornyhead turbot	Liver	PCB	PCB 149	2.6	ppb
2010-4	SD21	3	Hornyhead turbot	Liver	PCB	PCB 153/168	11.5	ppb
2010-4	SD21	3	Hornyhead turbot	Liver	PCB	PCB 180	4.2	ppb
2010-4	SD21	3	Hornyhead turbot	Liver	PCB	PCB 187	5.95	ppb

Appendix G

Supporting Data

2010 Regional Stations

Sediment Conditions

Appendix G.1

Summary of the constituents that make up total DDT, total HCH, total PAH, and total PCB in each sediment sample collected as part of the 2010 regional survey.

Station	Class	Constituent	Value	Units
8004	DDT	p,p-DDE	360	ppt
8005	DDT	p,p-DDE	200	ppt
8005	PCB	PCB 138	42	ppt
8006	DDT	p,p-DDE	390	ppt
8007	DDT	p,p-DDE	<MDL	ppt
8008	DDT	p,p-DDE	170	ppt
8009	DDT	o,p-DDD	45	ppt
8009	DDT	p,p-DDE	340	ppt
8011	DDT	p,p-DDE	440	ppt
8011	PCB	PCB 153/168	38	ppt
8012	DDT	p,p-DDD	1300	ppt
8012	DDT	p,p-DDE	1500	ppt
8012	DDT	p,p-DDT	590	ppt
8012	HCH	HCH, Beta isomer	4800	ppt
8012	HCH	HCH, Delta isomer	3700	ppt
8014	DDT	p,p-DDE	280	ppt
8015	DDT	p,p-DDE	<MDL	ppt
8015	PCB	PCB 114	<MDL	ppt
8015	PCB	PCB 153/168	<MDL	ppt
8019	DDT	p,p-DDD	130	ppt
8019	DDT	p,p-DDE	930	ppt
8019	DDT	p,p-DDT	330	ppt
8019	PAH	Benzo[A]pyrene	24.4	ppb
8019	PCB	PCB 138	36	ppt
8019	PCB	PCB 149	160	ppt
8019	PCB	PCB 153/168	120	ppt
8020	DDT	p,p-DDE	180	ppt
8022	DDT	p,p-DDE	560	ppt
8022	PCB	PCB 153/168	100	ppt
8024	DDT	p,p-DDE	250	ppt
8024	PAH	3,4-benzo(B)fluoranthene	26.6	ppb
8024	PAH	Benzo[A]pyrene	24.5	ppb
8024	PAH	Benzo[G,H,I]perylene	20.3	ppb
8024	PCB	PCB 70	250	ppt
8024	PCB	PCB 105	45	ppt
8024	PCB	PCB 110	130	ppt
8024	PCB	PCB 118	130	ppt
8024	PCB	PCB 138	110	ppt

<MDL=Average of lab duplicates below MDL (see City of San Diego 2011)

Appendix G.1 *continued*

Station	Class	Constituent	Value	Units
8024	PCB	PCB 149	200	ppt
8024	PCB	PCB 151	39	ppt
8024	PCB	PCB 153/168	140	ppt
8024	PCB	PCB 177	200	ppt
8028	DDT	o,p-DDD	270	ppt
8028	DDT	o,p-DDT	350	ppt
8028	DDT	p,p-DDD	2000	ppt
8028	DDT	p,p-DDE	2300	ppt
8028	DDT	p,p-DDT	71,000	ppt
8028	PAH	3,4-benzo(B)fluoranthene	25.3	ppb
8028	PAH	Benzo[A]anthracene	29.1	ppb
8028	PAH	Fluoranthene	21.6	ppb
8028	PAH	Pyrene	25	ppb
8028	PCB	PCB 52	590	ppt
8028	PCB	PCB 66	81	ppt
8028	PCB	PCB 70	160	ppt
8028	PCB	PCB 99	310	ppt
8028	PCB	PCB 101	990	ppt
8028	PCB	PCB 105	270	ppt
8028	PCB	PCB 110	530	ppt
8028	PCB	PCB 118	370	ppt
8028	PCB	PCB 128	140	ppt
8028	PCB	PCB 138	400	ppt
8028	PCB	PCB 149	490	ppt
8028	PCB	PCB 153/168	310	ppt
8028	PCB	PCB 156	81	ppt
8028	PCB	PCB 170	160	ppt
8028	PCB	PCB 177	170	ppt
8028	PCB	PCB 180	220	ppt
8028	PCB	PCB 187	110	ppt
8028	PCB	PCB 206	190	ppt
8030	DDT	p,p-DDE	270	ppt
8038	DDT	p,p-DDE	230	ppt
8039	DDT	p,p-DDE	220	ppt
8040	DDT	p,p-DDE	100	ppt
8043	DDT	p,p-DDE	200	ppt
8043	PCB	PCB 206	290	ppt
8045	DDT	p,p-DDE	290	ppt
8045	PCB	PCB 52	290	ppt
8045	PCB	PCB 66	200	ppt
8045	PCB	PCB 70	670	ppt

Appendix G.1 *continued*

Station	Class	Constituent	Value	Units
8045	PCB	PCB 74	200	ppt
8045	PCB	PCB 87	540	ppt
8045	PCB	PCB 99	330	ppt
8045	PCB	PCB 101	1400	ppt
8045	PCB	PCB 105	230	ppt
8045	PCB	PCB 110	930	ppt
8045	PCB	PCB 118	610	ppt
8045	PCB	PCB 128	140	ppt
8045	PCB	PCB 138	620	ppt
8045	PCB	PCB 149	590	ppt
8045	PCB	PCB 153/168	230	ppt
8045	PCB	PCB 156	55	ppt
8045	PCB	PCB 158	80	ppt
8045	PCB	PCB 180	220	ppt

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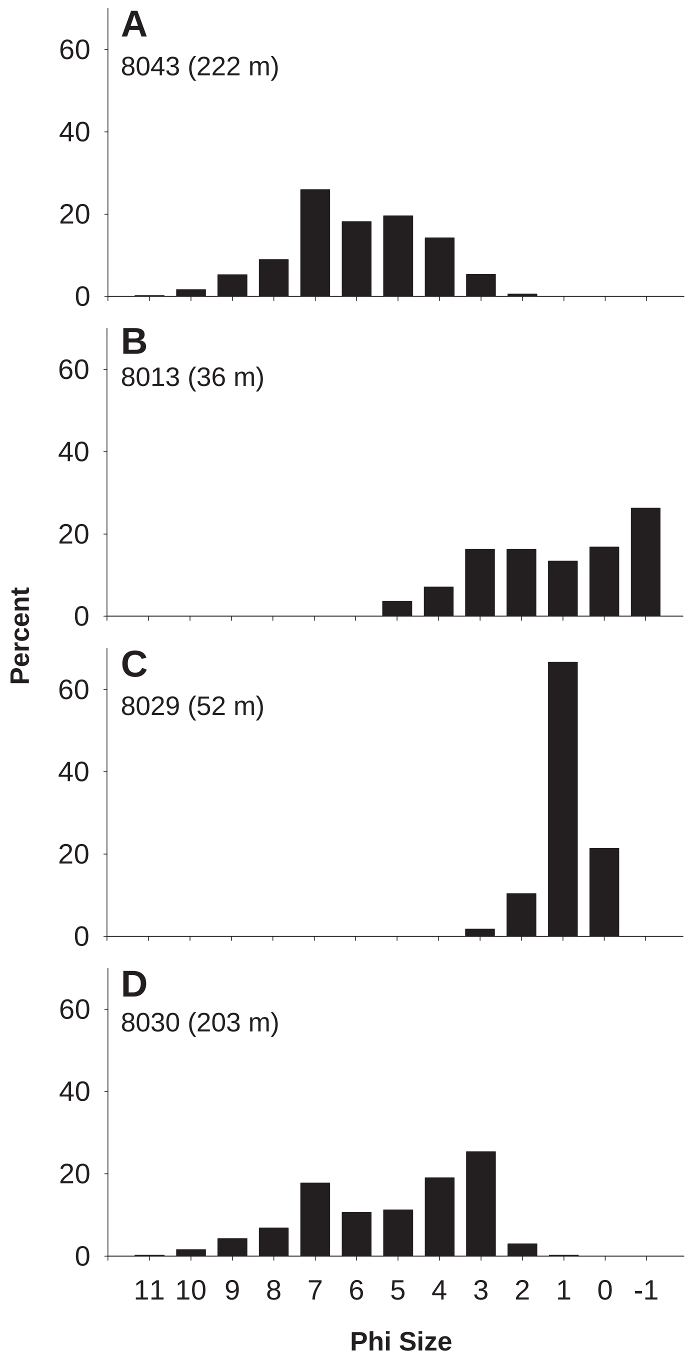
Appendix G.2

Summary of particle size parameters for the 2010 regional survey stations. Silt and clay fractions are indiscernable for samples analyzed by sieve. Visual observations of sediments were made in the field at the time of collection as well as on the sieved “grunge” (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis). SD = standard deviation; abbreviated visual observations are: Sh = shell hash; G = gravel; R = rock; Od = organic debris; Rrs = red relict sand; Wt = worm tubes; Cs = coarse sand; Cbs = coarse black sand; Ct = chaetopterid tubes.

	Station	Depth (m)	Mean (mm)	Mean (phi)	SD (phi)	Median (phi)	Coarse (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	Visual Observations
Inner Shelf	8016	9	0.210	2.25	0.59	2.37	0.0	99.5	0.5	0.0	0.5	Sh
	8047	9	0.315	1.67	1.05	1.84	7.7	92.3	0.0	0.0	0.0	Sh
	8010	10	0.186	2.42	0.49	2.45	0.0	98.7	1.3	0.0	1.3	Wt, Sh
	8017	12	0.177	2.50	0.57	2.63	0.0	97.8	2.2	0.0	2.2	G, Od, Wt, Sh
	8025	17	0.113	3.15	0.79	3.02	0.0	87.4	12.1	0.5	12.6	Od, Wt, Sh
	8027	21	0.115	3.13	0.58	3.05	0.0	90.7	9.1	0.2	9.3	Od, Wt
	8033	22	0.103	3.28	1.20	3.67	11.6	81.9	—	—	6.6	Sh
	8021	24	0.124	3.01	0.73	2.94	0.0	92.6	7.0	0.3	7.4	Od, Wt
Mid-shelf	8023	31	0.591	0.76	1.40	1.03	21.8	72.0	—	—	6.1	Cs, G, R, Sh
	8032	33	0.107	3.23	1.08	3.15	0.0	82.1	17.1	0.7	17.9	Od, Wt
	8013	36	0.623	0.68	1.68	0.52	43.1	53.1	—	—	3.7	Sh, G
	8034	38	0.591	0.76	0.68	0.68	11.4	88.6	0.0	0.0	0.0	Rrs, Sh
	8003	40	0.109	3.20	1.11	2.97	0.0	82.7	16.2	1.1	17.3	Od, Wt
	8001	50	0.073	3.78	1.33	3.50	0.0	70.1	27.7	2.2	29.9	Od, Sh
	8009	52	0.055	4.18	1.48	3.73	0.0	58.9	38.7	2.5	41.1	Od, Wt, Sh
	8029	52	0.786	0.35	0.49	0.26	21.4	78.6	0.0	0.0	0.0	Cbs
	8007	58	0.048	4.38	1.57	3.93	0.0	52.2	45.0	2.8	47.8	Od, Wt, Sh
	8005	62	0.057	4.14	1.50	3.67	0.0	63.6	34.2	2.2	36.4	Od, Wt, Sh
	8011	78	0.040	4.63	1.50	4.27	0.0	40.2	56.3	3.5	59.8	Wt, Od
	8028	80	0.053	4.23	1.63	3.74	0.0	56.3	40.7	3.0	43.7	G, Cs, Od, Wt, Sh
	8019	81	0.044	4.51	1.54	4.14	0.0	45.2	51.7	3.1	54.8	Od, Wt, Sh
	8006	84	0.040	4.63	1.59	4.29	0.0	41.7	54.8	3.6	58.3	Od, Wt, Sh
	8022	85	0.051	4.30	1.58	3.90	0.0	53.1	43.7	3.2	46.9	G, Sh
	8002	94	0.057	4.15	1.49	3.62	0.0	62.6	34.6	2.8	37.4	G, Sh
	8020	96	0.067	3.91	1.39	3.47	0.0	66.5	31.4	2.1	33.5	Od, Wt, Sh
	8024	101	0.701	0.51	1.00	0.52	27.2	69.1	—	—	3.7	Sh, G, Cs, R
	8014	112	0.056	4.16	1.58	3.62	0.0	60.5	36.7	2.8	39.5	Od, Wt, Sh
Outer Shelf	8012	123	0.060	4.06	1.49	3.51	0.0	64.3	33.2	2.6	35.7	Sh, Cbs
	8008	125	0.089	3.49	1.65	2.81	0.0	76.0	21.5	2.5	24.0	Sh, G, R
	8026	155	0.091	3.47	1.70	2.62	0.0	76.4	21.7	1.9	23.6	Cs, Sh
	8018	161	0.193	2.37	1.95	2.12	4.1	78.9	15.3	1.7	17.0	G, Sh
	8015	167	0.040	4.66	1.64	4.22	0.0	43.5	52.2	4.3	56.5	Od, Ct
	8004	196	0.040	4.63	1.65	4.13	0.0	46.1	49.4	4.5	53.9	Od, Ct
Upper Slope	8030	203	0.044	4.52	1.97	4.19	0.0	47.6	46.4	6.0	52.4	Od, Ct, Sh
	8045	212	0.033	4.93	1.66	4.66	0.0	34.0	60.6	5.4	66.0	Od, Ct, Sh
	8043	222	0.023	5.46	1.63	5.59	0.0	20.1	72.7	7.2	79.9	Od, Ct, Sh
	8038	263	0.034	4.87	1.73	4.65	0.0	38.3	56.5	5.2	61.7	Od, Wt, Sh
	8037	317	0.025	5.35	1.55	5.45	0.0	21.2	73.4	5.3	78.8	Od, Wt
	8040	421	0.024	5.38	1.60	5.59	0.0	22.0	72.5	5.6	78.0	Wt
	8039	433	0.034	4.89	1.67	4.76	0.0	35.8	59.9	4.3	64.2	G, Od, Wt



Appendix G.3

Select histograms illustrating particle size distributions of regional sediments in 2010. (A) highest percent fines (79.9%); (B) highest percent coarse (43.1%; this sample was sieved, so the bar at phi 5 represents all material finer than phi 4, see text); (C) most well sorted (SD = 0.5); (D) most poorly sorted (SD = 2.0).

Appendix G.4

Concentrations of chemical analytes in sediments from the 2010 regional stations. ERL = Effects Range Low threshold value; ERM = Effects Range Median threshold value; see Appendix C.2 for MDLs, parameter abbreviations, and periodic table symbols. Values that exceed ERL or ERM values are in bold.

	Station	Depth (m)	Sulfides (ppm)	TN (% weight)	TOC (% weight)	tHCH (ppt)	tDDT (ppt)	HCB (ppt)	tPCB (ppt)	tPAH (ppb)
Inner Shelf	8016	9	nd	0.014	0.070	nd	nd	nd	nd	nd
	8047	9	0.96	0.013	0.081	nd	nd	nd	nd	nd
	8010	10	3.69	0.017	0.086	nd	nd	nd	nd	nd
	8017	12	2.52	0.023	0.042	nd	nd	nd	nd	nd
	8025	17	0.20	0.020	0.130	nd	nd	nd	nd	nd
	8027	21	nd	0.019	0.125	nd	nd	nd	nd	nd
	8033	22	9.07	0.020	0.157	nd	nd	nd	nd	nd
	8021	24	2.90	0.021	0.139	nd	nd	50	nd	nd
Mid-shelf	8023	31	0.69	0.043	2.310	nd	nd	nd	nd	nd
	8032	33	nd	0.024	0.185	nd	nd	62	nd	nd
	8013	36	10.40	0.045	4.320	nd	nd	nd	nd	nd
	8034	38	0.31	0.010	0.027	nd	nd	nd	nd	nd
	8003	40	14.60	0.041	0.307	nd	nd	nd	nd	nd
	8001	50	4.08	0.049	0.463	nd	nd	27	nd	nd
	8009	52	6.31	0.061	0.552	nd	385	nd	nd	nd
	8029	52	0.56	0.010	0.022	nd	nd	nd	nd	nd
	8007	58	2.60	0.081	0.729	nd	< MDL	nd	nd	nd
	8005	62	2.59	0.061	0.546	nd	200	nd	42	nd
	8011	78	6.88	0.091	0.842	nd	440	nd	38	nd
	8028	80	3.91	0.077	0.738	nd	**75,920**	nd	5572	101.0
	8019	81	3.46	0.104	0.902	nd	1390	nd	316	24.4
	8006	84	2.23	0.097	0.876	nd	390	nd	nd	nd
	8022	85	7.00	0.071	0.563	nd	560	81	100	nd
	8002	94	1.40	0.058	0.516	nd	nd	nd	nd	nd
	8020	96	4.15	0.047	0.395	nd	180	nd	nd	nd
	8024	101	5.36	0.053	0.515	nd	250	nd	1244	71.4
	8014	112	3.60	0.053	0.540	nd	280	nd	nd	nd
Outer Shelf	8012	123	3.33	0.063	0.646	8500	**3390**	nd	nd	nd
	8008	125	2.97	0.069	4.470	nd	170	nd	nd	nd
	8026	155	2.21	0.041	1.530	nd	nd	nd	nd	nd
	8018	161	1.60	0.050	1.480	nd	nd	nd	nd	nd
	8015	167	24.10	0.115	1.150	nd	< MDL	nd	< MDL	nd
	8004	196	3.16	0.093	0.877	nd	360	nd	nd	nd
Upper Slope	8030	203	4.00	0.105	1.590	nd	270	nd	nd	nd
	8045	212	17.50	0.131	1.510	nd	290	nd	7335	nd
	8043	222	10.70	0.212	2.650	nd	200	nd	290	nd
	8038	263	12.90	0.145	1.730	nd	230	nd	nd	nd
	8037	317	11.60	0.222	2.740	nd	nd	nd	nd	nd
	8040	421	12.90	0.198	2.080	nd	100	nd	nd	nd
	8039	433	2.30	0.149	1.800	nd	220	nd	nd	nd
		ERL:	na	na	na	na	1580	na	na	4022
		ERM:	na	na	na	na	46,100	na	na	44,792

nd = not detected; na = not available; < MDL = average of lab duplicates below MDL (see City of San Diego 2011)

Appendix G.4 *continued*

	Station	Depth (m)	Metals (ppm)								
			Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe
Inner Shelf	8016	9	2370	0.42	1.16	10.90	nd	nd	5.9	0.29	3670
	8047	9	2020	nd	1.20	8.49	nd	nd	5.1	4.32	4340
	8010	10	3410	nd	1.11	21.60	0.04	nd	5.4	1.12	4520
	8017	12	2090	nd	1.24	14.10	nd	nd	4.5	4.54	3400
	8025	17	3780	0.40	1.58	15.00	0.02	0.06	9.8	1.53	4130
	8027	21	3680	0.43	1.51	15.30	0.06	nd	9.0	1.19	3830
	8033	22	4410	0.46	1.94	32.90	0.04	nd	10.6	2.35	5340
	8021	24	3490	nd	1.72	19.90	nd	nd	6.9	5.70	5060
Mid-shelf	8023	31	4750	0.52	6.41	22.50	0.12	0.17	13.3	10.40	17,700
	8032	33	4690	0.45	1.62	27.00	0.04	nd	11.8	2.49	5760
	8013	36	2150	nd	2.39	14.10	0.05	0.17	6.9	2.84	4350
	8034	38	1180	nd	5.10	2.79	nd	nd	10.1	3.94	6540
	8003	40	8970	0.55	2.78	57.50	0.14	0.16	14.6	7.09	10,800
	8001	50	7600	0.51	3.60	52.70	0.13	nd	18.8	6.26	11,900
	8009	52	7710	nd	3.72	52.60	0.17	0.22	17.4	8.67	12,800
	8029	52	1020	nd	2.48	1.93	0.04	nd	3.5	0.55	3170
	8007	58	9370	0.41	3.89	57.30	0.20	0.24	19.6	10.50	14,300
	8005	62	9530	0.54	3.33	46.30	0.16	0.16	15.8	6.98	11,200
	8011	78	10,200	0.51	4.25	57.20	0.22	0.12	21.1	11.90	15,700
	8028	80	12,000	0.65	3.95	44.90	0.19	0.12	18.0	15.70	12,100
	8019	81	7190	0.39	3.82	47.00	0.21	0.16	19.2	12.70	12,400
	8006	84	7450	0.37	4.15	49.40	0.20	0.11	18.2	10.20	13,300
	8022	85	14,400	0.69	3.86	59.40	0.22	0.13	19.9	13.40	14,600
	8002	94	9030	0.51	3.20	50.20	0.21	0.20	17.6	7.71	13,300
	8020	96	4750	nd	2.06	26.50	0.12	0.08	11.7	6.02	8420
	8024	101	10,300	0.32	3.38	54.50	nd	0.13	15.4	13.60	15,900
	8014	112	4510	nd	2.87	28.50	0.14	0.10	13.2	7.09	9060
Outer Shelf	8012	123	4560	<MDL	2.24	27.20	0.13	0.13	12.2	6.26	8310
	8008	125	4760	nd	5.41	16.70	0.29	0.15	25.8	5.30	21,100
	8026	155	4540	0.38	3.17	16.20	0.18	0.18	19.6	4.21	9460
	8018	161	5790	0.62	5.46	86.60	0.32	0.16	30.2	3.96	13,700
	8015	167	7880	0.44	2.73	61.30	0.20	0.12	18.5	12.50	13,800
	8004	196	12,900	0.66	2.56	52.50	0.23	0.48	22.3	12.00	14,700
Upper Slope	8030	203	11,100	0.58	3.54	50.40	0.25	0.22	22.8	12.50	14,600
	8045	212	9170	0.42	2.96	57.00	0.24	0.31	23.2	14.80	14,600
	8043	222	18,000	2.17	3.77	80.10	0.33	0.32	32.4	31.20	19,900
	8038	263	8880	0.44	2.82	55.10	0.25	0.39	23.4	14.70	14,700
	8037	317	18,100	0.89	2.97	87.60	0.33	0.36	32.1	24.40	18,600
	8040	421	19,400	0.88	4.66	100.00	0.37	0.62	33.4	22.80	21,400
	8039	433	14,100	0.83	2.22	81.40	0.29	0.49	30.5	16.90	17,100
		ERL:	na	na	8.2	na	na	1.2	81	34	na
		ERM:	na	na	70	na	na	9.6	370	270	na

nd = not detected; na = not available; <MDL = average of lab duplicates below MDL (see City of San Diego 2011)

Appendix G.4 *continued*

	Station	Depth (m)	Metals (ppm) Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
Inner Shelf	8016	9	2.20	38.1	nd	1.13	nd	0.30	nd	nd	7.5
	8047	9	1.14	42.1	nd	0.91	nd	nd	nd	nd	6.4
	8010	10	0.89	67.7	0.055	1.45	nd	nd	nd	0.4	13.2
	8017	12	0.99	35.6	nd	1.17	nd	nd	nd	<MDL	7.8
	8025	17	3.35	38.8	0.003	2.24	nd	nd	2.0	nd	10.3
	8027	21	2.99	36.4	nd	1.94	nd	nd	nd	nd	8.9
	8033	22	4.16	50.0	0.003	2.77	nd	nd	nd	nd	12.7
	8021	24	2.60	53.8	0.013	1.93	nd	nd	nd	0.4	13.9
Mid-shelf	8023	31	**91.60**	235.0	nd	4.22	nd	nd	nd	1.7	39.0
	8032	33	4.50	47.7	0.005	3.41	0.243	nd	nd	nd	13.1
	8013	36	1.93	36.6	0.016	2.29	nd	nd	nd	0.3	11.1
	8034	38	2.37	14.6	nd	0.77	nd	nd	nd	0.3	6.4
	8003	40	2.87	119.0	0.006	5.51	0.530	nd	nd	0.6	31.9
	8001	50	8.25	93.7	0.007	5.49	nd	0.33	nd	0.5	29.0
	8009	52	5.18	111.0	0.043	6.59	0.250	nd	nd	0.9	35.1
	8029	52	1.29	8.2	nd	0.88	nd	nd	nd	nd	3.9
	8007	58	5.74	119.0	0.037	7.79	0.250	nd	nd	1.0	41.3
	8005	62	4.31	106.0	0.021	6.39	nd	nd	nd	0.9	29.4
	8011	78	6.62	117.0	0.041	9.54	0.750	nd	nd	1.3	38.9
	8028	80	9.36	102.0	0.062	8.48	0.276	nd	nd	1.5	40.9
	8019	81	5.67	92.6	0.053	10.40	0.310	nd	nd	0.9	34.9
	8006	84	6.24	103.0	0.074	8.59	0.470	nd	nd	0.9	34.7
	8022	85	6.43	123.0	0.043	9.49	0.270	nd	nd	1.3	37.8
	8002	94	4.97	94.8	0.017	6.97	0.320	nd	nd	0.9	30.8
	8020	96	3.65	55.8	0.023	5.26	0.400	nd	nd	0.7	20.4
	8024	101	5.39	112.0	0.043	6.53	0.266	nd	nd	1.0	35.1
	8014	112	4.23	61.0	0.025	6.08	nd	nd	nd	0.6	24.7
Outer Shelf	8012	123	4.01	61.3	0.025	6.05	0.440	nd	nd	0.6	22.6
	8008	125	4.27	43.7	0.016	5.29	0.350	nd	nd	0.5	34.2
	8026	155	2.20	27.2	0.010	4.82	0.300	nd	nd	0.5	17.4
	8018	161	2.44	24.9	0.005	4.73	nd	nd	nd	0.4	21.6
	8015	167	7.27	111.0	0.051	9.46	0.370	nd	nd	1.0	37.6
	8004	196	5.26	121.0	0.029	10.90	0.360	nd	nd	1.1	38.7
Upper Slope	8030	203	4.81	83.2	0.030	11.20	0.551	nd	nd	1.3	34.7
	8045	212	5.69	113.0	0.029	13.60	0.410	nd	nd	0.9	42.4
	8043	222	9.39	143.0	0.089	20.60	1.010	nd	nd	2.6	57.7
	8038	263	5.79	104.0	0.042	13.10	0.650	nd	nd	0.9	41.5
	8037	317	6.49	139.0	0.058	**21.20**	1.160	nd	nd	1.5	54.1
	8040	421	7.28	160.0	0.045	18.10	1.130	nd	nd	1.5	58.8
	8039	433	4.87	115.0	0.071	15.00	0.880	nd	nd	1.0	45.6
		ERL:	46.7	na	0.15	20.9	na	1	na	na	150
		ERM:	218	na	0.71	51.6	na	3.7	na	na	410

nd = not detected; na = not available; <MDL = average of lab duplicates below MDL (see City of San Diego 2011)

Appendix G.5

Summary of the parameters that distinguish between each cluster group according to SIMPER analysis. Shown are the five parameters with the greatest percent contribution to overall average squared Euclidean distance between each group. See Table 8.3 for units of each parameter.

Parameter	Average Squared Distance/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups A & B			
Lead	22.6	26.0	26.0
Median Phi	6.0	7.4	33.5
Selenium	4.2	7.2	40.7
Total Nitrogen	2.6	5.6	46.3
Mercury	1.8	5.6	51.8
Groups A & C			
Total DDT	373.9	45.5	45.5
Selenium	3.2	6.2	51.7
Cadmium	1.3	6.0	57.8
Total Nitrogen	2.1	5.6	63.3
Antimony	0.6	5.0	68.3
Groups A & D			
Nickel	3.5	6.7	6.7
Total Nitrogen	3.2	6.7	13.3
Copper	2.1	6.5	19.8
Selenium	4.2	6.2	26.1
Aluminum	3.3	6.1	32.2
Groups A & E			
Antimony	0.8	10.3	10.3
Total Nitrogen	1.8	8.0	18.3
Copper	1.3	8.0	26.3
Selenium	1.7	7.9	34.2
Nickel	1.8	7.1	41.3
Groups B & C			
Total DDT	*	36.5	36.5
Lead	*	31.7	68.2
Manganese	*	7.4	75.6
Mercury	*	6.0	81.6
Median Phi	*	3.6	85.2
Groups B & D			
Lead	36.9	39.3	39.3
Manganese	6.1	17.1	56.4
Arsenic	2.9	12.5	68.9
Tin	4.8	7.3	76.2
Iron	6.8	5.8	82.0

* Statistic is undefined because standard deviation = 0

Appendix G.5 *continued*

Parameter	Average Squared Distance/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups B & E			
Lead	28.7	48.8	48.8
Manganese	2.2	12.7	61.5
Arsenic	2.0	7.4	68.9
Median Phi	2.1	5.1	74.0
Tin	1.7	3.0	77.0
Groups C & D			
Total DDT	*	43.9	43.9
Tin	4.2	6.4	50.2
Mercury	2.8	5.9	56.1
Zinc	4.8	4.8	60.9
Sorting (SD)	1.6	4.3	65.2
Groups C & E			
Total DDT	52.3	73.7	73.7
Mercury	1.2	4.1	77.7
Tin	1.4	2.7	80.5
Sulfides	0.4	2.4	82.9
Copper	1.1	2.0	84.9
Groups D & E			
Sorting (SD)	1.3	8.9	8.9
Iron	1.5	6.7	15.6
Beryllium	1.5	6.4	22.0
Zinc	1.8	6.0	27.9
Arsenic	1.0	5.9	33.8

* Statistic is undefined because standard deviation = 0

Appendix H

Supporting Data

2010 Regional Stations

Macrobenthic Communities

Appendix H.1

Summary of taxa that distinguish between each cluster group according to SIMPER analysis. Shown are the five taxa with the greatest percent contribution to overall average Bray-Curtis dissimilarity between each group.

Species/Taxa	Average Dissimilarity/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups A & B			
Maldane sarsi	4.2	4.3	4.3
Gibberosus myersi	1.1	4.1	8.5
Yoldiella nana	4.5	3.8	12.3
Eclysippe trilobata	4.1	3.7	16.0
Metharpinia jonesi	2.4	3.3	19.3
Groups A & C			
Gibberosus myersi	1.1	3.3	3.3
Spiophanes norrisi	1.2	3.0	6.2
Metharpinia jonesi	2.3	2.9	9.1
Spio maculata	1.4	2.6	11.7
Actiniaria	0.8	2.4	14.1
Groups A & D			
Spiophanes norrisi	1.5	3.6	3.6
Gibberosus myersi	1.0	2.1	5.7
Metharpinia jonesi	1.8	1.8	7.5
Spiophanes duplex	1.1	1.7	9.2
Apoprionospio pygmaea	0.9	1.5	10.7
Groups A & E			
Aphelochaeta glandaria Cmplx	5.5	4.2	4.2
Gibberosus myersi	1.1	3.0	7.1
Monticellina siblina	3.6	2.8	9.9
Chaetozone sp SD5	5.5	2.6	12.5
Metharpinia jonesi	2.1	2.4	14.9
Groups A & F			
Gibberosus myersi	1.1	3.2	3.2
Metharpinia jonesi	2.4	2.6	5.7
Actiniaria	0.8	2.2	7.9
Tellina modesta	3.3	2.1	10.0
Owenia collaris	0.6	2.1	12.1
Groups A & G			
Amphiodia urtica	2.0	3.6	3.6
Gibberosus myersi	1.2	2.1	5.7
Metharpinia jonesi	2.7	1.7	7.4
Actiniaria	0.8	1.5	8.8
Owenia collaris	0.6	1.5	10.3
Groups B & C			
Maldane sarsi	4.5	4.1	4.1

Appendix H.1 *continued*

Species/Taxa	Average Dissimilarity/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups B & C			
Spiophanes norrisi	1.3	4.0	8.1
Yoldiella nana	5.0	3.7	11.8
Eclysippe trilobata	4.4	3.5	15.3
Spio maculata	1.4	2.9	18.1
Groups B & D			
Spiophanes norrisi	1.7	4.5	4.5
Maldane sarsi	2.1	2.4	6.9
Yoldiella nana	2.1	2.2	9.1
Eclysippe trilobata	2.1	2.1	11.2
Spiophanes duplex	1.1	1.8	13.0
Groups B & E			
Aphelochaeta glandaria Cmplx	8.9	4.8	4.8
Maldane sarsi	3.0	3.6	8.4
Yoldiella nana	3.1	3.2	11.6
Monticellina siblina	4.0	3.2	14.8
Chaetozone sp SD5	13.0	3.0	17.7
Groups B & F			
Yoldiella nana	4.7	3.8	3.8
Eclysippe trilobata	4.2	3.7	7.5
Maldane sarsi	2.2	2.6	10.1
Spiophanes kimballi	1.9	2.4	12.5
Myriochele gracilis	1.2	2.1	14.6
Groups B & G			
Amphiodia urtica	2.0	4.3	4.3
Yoldiella nana	5.0	2.3	6.6
Eclysippe trilobata	3.3	2.1	8.7
Maldane sarsi	3.4	2.1	10.7
Axinopsida serricata	1.2	1.7	12.4
Groups C & D			
Spiophanes norrisi	1.4	3.2	3.2
Spiophanes duplex	1.1	1.8	5.0
Spio maculata	1.2	1.8	6.8
Apoprionospio pygmaea	0.7	1.5	8.3
Mediomastus sp	2.2	1.4	9.7
Groups C & E			
Aphelochaeta glandaria Cmplx	6.0	4.4	4.4
Spiophanes norrisi	1.5	3.8	8.1
Monticellina siblina	3.8	2.5	10.6

Appendix H.1 *continued*

Species/Taxa	Average Dissimilarity/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups C & E			
Spio maculata	1.3	2.3	12.9
Chaetozone sp SD5	3.4	2.0	14.9
Groups C & F			
Spiophanes norrisi	1.7	3.9	3.9
Spio maculata	1.5	2.4	6.2
Eurydice caudata	3.8	1.9	8.2
Spiophanes kimballi	1.8	1.9	10.1
Lanassa venusta venusta	1.0	1.6	11.7
Groups C & G			
Amphiodia urtica	1.9	3.5	3.5
Spiophanes norrisi	1.5	2.6	6.1
Spio maculata	1.4	1.7	7.8
Axinopsida serricata	1.2	1.5	9.3
Eurydice caudata	2.9	1.3	10.6
Groups D & E			
Spiophanes norrisi	1.8	4.4	4.4
Aphelochaeta glandaria Cmplx	2.4	2.8	7.2
Spiophanes duplex	1.1	1.5	8.7
Chaetozone sp SD5	1.7	1.4	10.1
Apoprionospio pygmaea	0.7	1.3	11.4
Groups D & F			
Spiophanes norrisi	1.9	4.3	4.3
Spiophanes duplex	1.1	1.5	5.9
Apoprionospio pygmaea	0.7	1.3	7.2
Monticellina siblina	1.0	1.3	8.5
Spiophanes kimballi	1.5	1.2	9.7
Groups D & G			
Spiophanes norrisi	1.8	3.5	3.5
Amphiodia urtica	1.7	2.6	6.0
Spiophanes duplex	1.1	1.1	7.2
Axinopsida serricata	1.1	1.1	8.3
Apoprionospio pygmaea	0.7	1.1	9.3
Groups E & F			
Aphelochaeta glandaria Cmplx	3.1	3.5	3.5
Monticellina siblina	3.7	3.0	6.5
Chaetozone sp SD5	4.0	2.8	9.3
Huxleyia munita	1.2	1.7	11.0
Spiophanes kimballi	1.4	1.4	12.4

Appendix H.1 *continued*

Species/Taxa	Average Dissimilarity/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups E & G			
Amphiodia urtica	1.9	3.8	3.8
Aphelochaeta glandaria Cmplx	3.3	2.8	6.6
Chaetozone sp SD5	3.6	2.0	8.6
Monticellina siblina	2.2	1.8	10.4
Axinopsida serricata	1.1	1.3	11.7
Groups F & G			
Amphiodia urtica	1.9	3.9	3.9
Axinopsida serricata	1.1	1.3	5.2
Spiophanes kimballi	1.7	1.3	6.5
Travisia brevis	1.6	1.2	7.7
Prionospio (*Prionospio*) *dubia*	2.2	1.2	8.8